THE ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOLUME XIV

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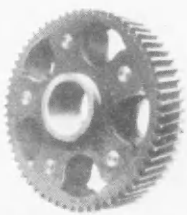

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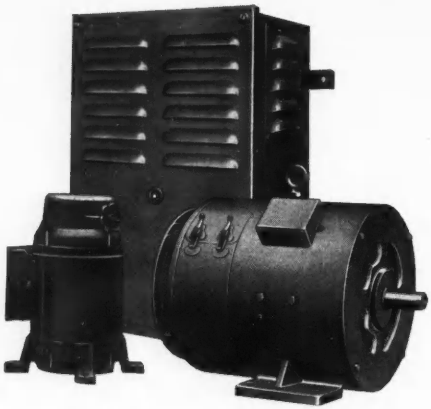

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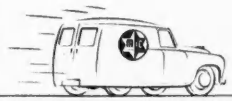

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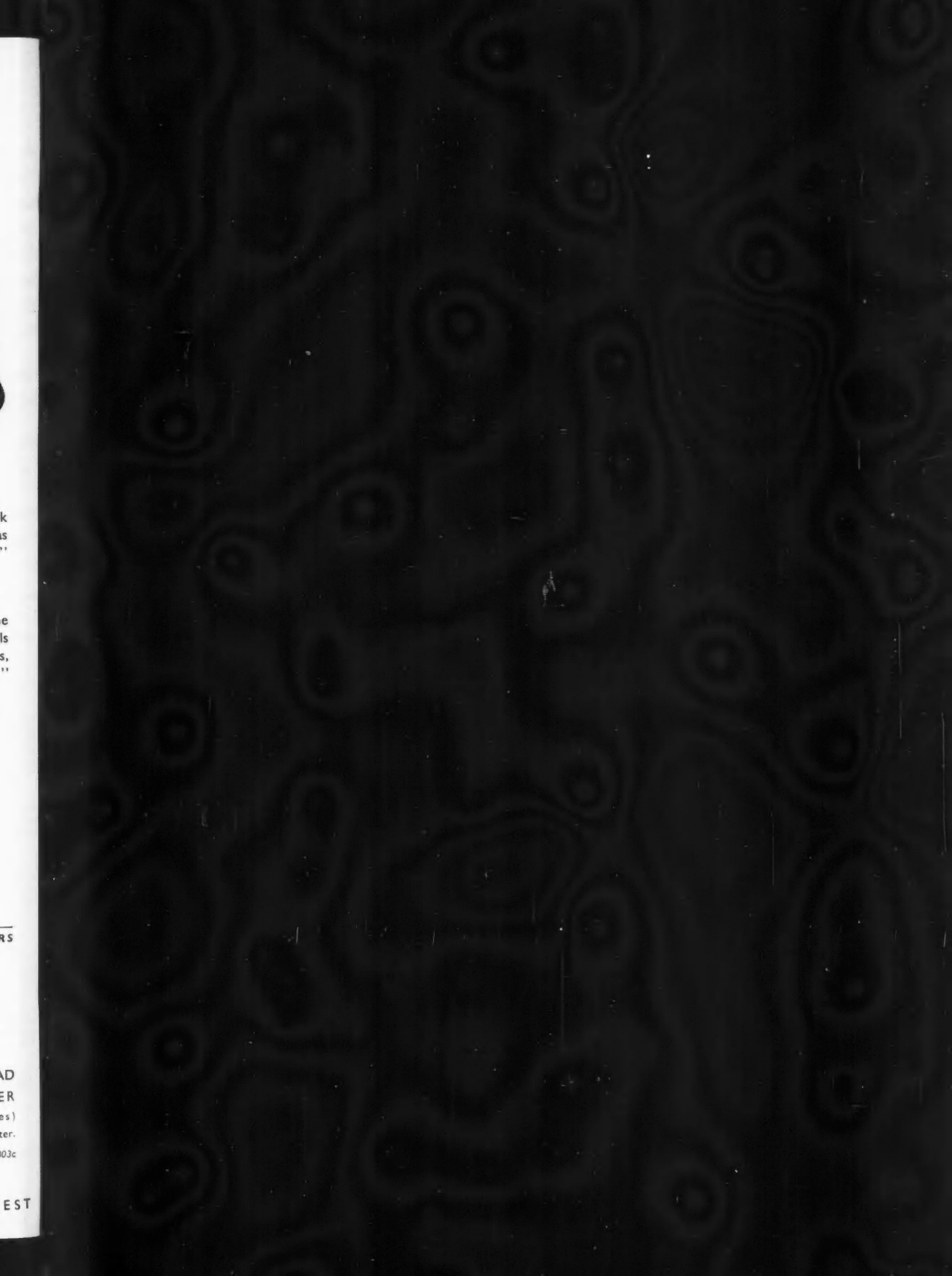

THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *SYNCHRONOUS HYSTERESIS MOTORS*

Synchronous hysteresis motors are simple and rugged units which are distinguished from other types of synchronous motors by the feature that they are capable of developing high starting torque and of synchronizing high inertia loads without complicated starting and accelerating equipment. Until recently the inferior qualities of available magnet steels limited the usefulness of this motor type. Applications were therefore restricted to drives requiring negligible power, such as electric clocks. With the introduction of superior chromium, tungsten and cobalt steels, and later the Alnicos, these limitations have now been overcome. At synchronous speed, the rotor and the rotating stator field of the synchronous hysteresis motor have zero relative velocity. Rotor magnetization lags behind the magnetomotoric force of the stator by an angle analogous to the power angle of a conventional synchronous motor. Unlike the conventional synchronous machine, however, a steady rotor field is induced in the permanent magnet rotor ring, rather than applied by a special direct current winding. The lag angle varies with the shaft torque, and is zero when total torque is zero. The maximum synchronous torque equals the torque generated just below synchronism. Available hysteresis motors can roughly be classified according to their efficiency. Units having efficiencies under one per cent are usually heavily geared down and find application to timing devices of various kinds. Units of efficiencies from 5 to 25 per cent are highly suitable for gramophones, especially because of their low noise level. Finally there are hysteresis motors of the closed slot variety which have efficiencies up to 75 per cent, although the normal range is from 20 to 45 per cent. In specially designed gyro motors efficiencies exceeding 80 per cent may be reached.

● *FRICTION BETWEEN ALUMINIUM AND OTHER METALS*

Very little information has hitherto been available on the coefficient of friction of aluminium against other metals in the absence of lubrication, excepting a three year old Japanese report. In this case the coefficient of friction was established by measuring the angle at which specimens commenced to slide down an inclined plane. The contact area of the specimens measured 20 × 20 mm and the load ranged only from 10 to 300 grams. It is gratifying to note that more useful data have now become available from another source, the experiments being concerned with much higher pressures ranging from 100 to 3,000 kg per sq. cm., under which the coefficients of friction, both static and dynamic, of aluminium and two Al-Cu-Mg alloys with different heat treatments against steel and an Al-Cu-Mg alloy were determined. In the apparatus used for testing, two small test blocks were pressed under a measured pressure against both sides of a test strip to which tension was applied to pull it through between the blocks at a constant rate of about one mm per second. The static and dynamic coefficients of friction were calculated from the loads required to start and continue respectively the pulling through of the test strip. The coefficient of friction against steel was always higher than that against the Al-Cu-Mg alloy. In passing from static to dynamic friction, the coefficient usually decreased by from 3 to 25 per cent. In the case of heat treated Al-Cu-Mg alloy blocks sliding over a strip of the same material the coefficient of dynamic friction was higher than that of static friction. With heat treated Al-Cu-Mg alloy sliding on steel, the difference between static and dynamic friction was less than with any of the other combinations, and the variation of the coefficient with pressure was likewise only moderate.

● *HIGH PURITY CHROMIUM*

A highly refined chromium metal which is malleable enough to be forged at extremely low temperatures, has been produced, it is reported. According to the report, two methods of producing high-purity chromium were tested: Reduction of chromium chloride by magnesium, and the hydrogen treatment of electrolytic chromium. Although the hydrogen-treatment method was found to be the most successful of the two, neither method produced a metal that could be bent at temperatures below 325 deg C. without cracking. The metal produced by refining electrolytic chromium in a hydrogen atmosphere at high temperature could be forged even at a temperature as low as that of liquid air, and in sheet form it could be spot-welded to chromium or to iron. Further evidence of its workability was furnished by

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rolling, drilling, sawing, grinding and filing it when cold. Although chromium cannot be said to have satisfactory ductility until it can be bent at sharp angles at ordinary temperatures without cracking, the report points out that twenty years ago no one knew that chromium could be worked under any conditions at all. In view of the enormous utility of chromium under high temperature and likewise under corrosive conditions, further achievements may well bring metallurgical technique to the threshold of a new era in the utilisation of chromium in chemical industries as well as in high temperature engineering.

● *NEW HEAT RESISTING ALLOY*

A heat resistant alloy has been developed which is claimed to be suitable for practical engineering applications at temperatures up to 2200 deg F. In developing this material the metallurgists had to solve a twofold problem, namely to develop an alloy of greater strength from an existing Ni-Cr-Fe base alloy known to have excellent properties up to 1900 deg F and then to improve its oxidation resistance in connection with the strengthening elements added. Without proper chemical balance to form a tight adherent oxide scale, the additions of such strengthening elements as molybdenum and vanadium and certain ranges of chromium and tungsten would result in a porous oxide which accelerates the oxidation of the alloy. The alloy evolved has the following composition: 0·44 per cent carbon, 26·3 per cent chromium, 46 per cent nickel, 1·36 per cent manganese, 0·99 per cent silicon and 5·28 per cent tungsten. Test data showed that the short time tensile strength of the material is superior to that of the standard commercial heat resistant alloys at temperatures of 1600 to 1800 deg F. Data were obtained with the new alloy for temperatures up to 2300 deg F, but similar values for other alloys are not available so that no comparison is possible, it is stated. Tensile creep and stress rupture properties were evaluated for the temperature range of 1800 to 2300 deg F in 100 deg intervals. A straight line relationship was found to exist between stress and both the creep rate and the rupture time. While the room temperature elongation and reduction of area of the alloy is not high, this is claimed not to be a detriment in the casting, welding and handling of the material. Oxidation resistance was tested by means of a 500 hour cycling test at 2200 deg F consisting of heating to 2200 deg F, cooling to 800 deg F and reheating, and so on, the cycle being repeated every 24 hours.

● *UNLUBRICATED BALL BEARINGS IN VACUUM*

A recent patent specification describes a ball bearing to be used under high vacuum in X-ray tubes having a rotary anode. It goes without saying that in this case ordinary lubricants cannot be used. To meet this difficulty it had originally been proposed to use unlubricated balls or rollers and races, but to cover them with an extremely thin coating of soft metal such as lead, although tin, cadmium, zinc or copper can also be used. It has now been found that still better results are obtained if the thin soft metal coating on balls and races consists of silver alloyed with lead, indium, or germanium, or if it consists of copper alloyed with silver, lead or aluminium. By using the silver alloy, it is possible to retain the excellent lubrication associated with silver while avoiding an undesirable modification of the vapour pressure characteristics. When using the copper alloy as lubricant for steel balls and races, the alloy should contain an amount of copper not exceeding that which corresponds to the eutectic mixture. In the case of the copper-silver alloy the amount of copper should not therefore exceed 28 per cent by weight, and preferably should not be less than 10 per cent. A convenient method of applying the soft metal lubricant was found in introducing an appropriate amount of metal powder into the bearing and driving it to roll the powder into a thin coherent layer on the races and on the balls. An alternative method consists in employing the vaporisation under vacuum technique. This process has the advantage that it is possible to control very precisely the thickness of the layer of lubricating metal produced, which of course is very important.

● *ALTERNATING CURRENT SOLENOIDS*

The a.c. solenoid is the least expensive and simplest electrical device for performing the control functions of automatic machines. The pull on solenoids should be perpendicular to the core in two planes when the core is seated, and it should not be much removed from this direction at any point along the core travel. The amount of power that can be built into a solenoid with a given temperature rise decreases rapidly with an increase in the length of the air gap; consequently the gap should be kept as small as is practical. When a solenoid is installed so that the load on the core decreases as it moves to the seated position, an extra spring load should be arranged so that the solenoid picks it up after the core has done its regular work. This arrangement serves to load the core so that it will not slam home as hard and will not develop residual magnetism nearly so fast. Another method makes use of a high resistance across the switch used to energize the solenoid. This connection impresses a feeble a.c. voltage across the solenoid whenever the device actuated by the solenoid is in the operating condition. This method may be used in installations where a small voltage across the solenoid does not interfere with other devices in the circuit. An a.c. solenoid takes a relatively large inrush current,

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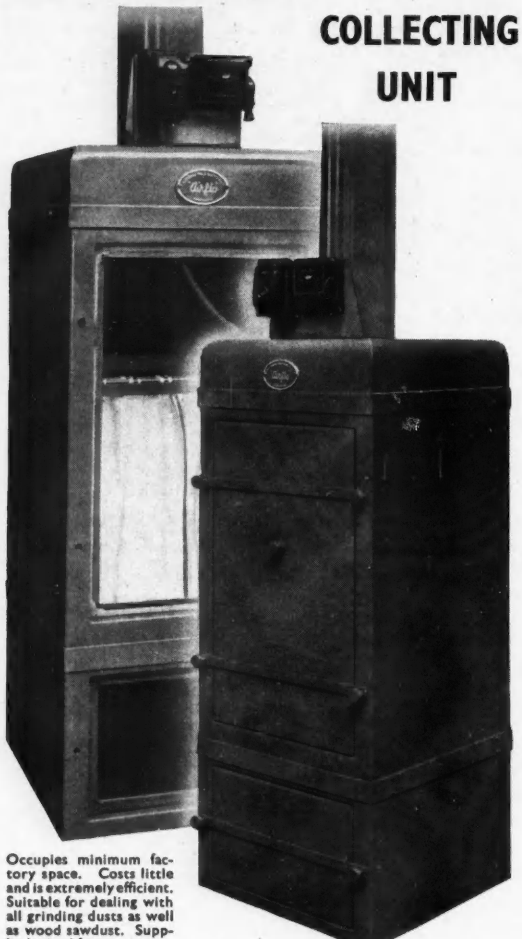

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and unless the terminal voltage can be maintained during this period, the solenoid may not get adequate current to enable it to pull the core to the seated position. A solenoid must be designed to pull immediately when energized or the high inrush current in the coil will increase the resistance so rapidly that the core cannot pull in and the solenoid will burn out. It is therefore important to overpower a solenoid enough so that it will close immediately upon being energized.

● *ARC LAMP CONTROL*

For the steady and satisfactory projection of motion pictures it is of the utmost importance for the arc, and in particular, the positive crater of the arc, to be kept constantly in the focus of the illumination system, consisting for example of a mirror or condenser lens system. Control systems have been developed in which an image of the arc is projected onto a radiation sensitive device, which in turn controls the carbon feed mechanism. These devices may incorporate thermocouples or photocells. In all such devices the radiation sensitive element is influenced by the difference in radiation intensity of the arc and the ends of the electrodes. As the ends of the electrodes become incandescent and as the arc and arc flame occupy an appreciable space and vary continually in intensity, it is difficult to effect a very exact control. A further disadvantage with the less expensive type of lamp is that the positive carbon is not rotated during burning and consequently the ends burn unevenly and with a deep crater which aggravates the control problem. According to a recent invention these shortcomings can be eliminated by blowing an annular stream of air from a hollow positive electrode holder so that the air envelops the positive electrode and flows toward the arc. This causes arc and flame to concentrate in the cylindrical space in front of the positive crater and to produce a relatively high contrast in radiation intensity between the end of the carbon and the crater itself, thus facilitating control. At the same time even consumption of the carbon is ensured.

● *WEAR RESISTANT ALUMINIUM FINISHES*

Procedures have been developed recently which produce anodic coatings on aluminium of greater thickness and increased density. Because of their substantial thickness, amounting to 0·001 to 0·005 in., and denser structure, these coatings support greater loads and overcome the shortcoming of thinner anodic coatings with regard to scratching and indentation-type abrasion. These hard, thick coatings are produced in acid-type electrolytes which are operated at low temperatures and high current densities. Operating techniques are particularly important insofar as consideration must be given to positive contact during the complete anodic oxidation period. Exceptional agitation and circulation of the electrolyte must be maintained in order to decrease the possibility of burning in areas of high current density. Hard coatings for aluminium alloys are naturally of considerable interest to the aircraft industry where a light metal with a hard wear-resistant finish offers a valuable replacement for parts produced from heavier metals of higher inherent hardness. Aluminium alloys with hard oxide coatings can be used for gears, pinions, bearing races, slides, various pistons, helicopter blade edges, and numerous other applications. These coatings offer also promising possibilities in other fields, as for instance in applications where aluminium alloys are exposed to the erosive influences of hot gases or liquids. Thus, they can be applied to advantage to high velocity pumps and blower impellers to minimize erosion. Hard chromium plating based on the zinc immersion process can be used to increase the surface hardness and wear resistance of aluminium alloys. Many applications involving wear or rubbing require the deposition of softer metals than chromium and for such purposes tin coatings are being used, which are applied by simple chemical immersion processes.

● *ULTRASONIC IMAGE PROCESS*

With the conventional type of instrument for the examination of solid bodies for flaws and fissures by means of ultrasonic waves, it is possible to ascertain the approximate location and extension of the fault; but it is not possible to accurately determine the contour of the fault. It is true that a method is now available, which makes it possible to produce an image of the fault. This method, usually termed the Pohlmann method after its inventor, is not always easily applied, however, to bodies of irregular shape. The suggestion has now been made to utilise thermo-sensitive pigments of the type used as temperature indicators, for the purpose of making visible faults in materials. In this method a screen covered with thermosensitive material is used in the same way as a fluorescent screen is used in conjunction with an X-ray tube. The thermosensitive material changes its colour in places where it is penetrated by ultrasonic waves, which by vibrating the pigment produce heat by friction and thus cause a local rise in temperature. The sensitivity of such a screen is claimed to be very high, especially if the screen is kept at a temperature only slightly below the temperature at which the colour change occurs, which in the material used lies at approximately 39 deg C. By maintaining the temperature slightly below the critical, a small amount of ultrasonic energy is needed to raise the local temperature above the critical and thus to produce the change-over in colour. This change in colour is

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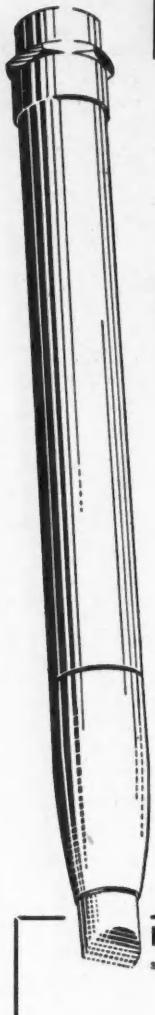

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not of course permanent, but the screen reverts to its original colour if the ultrasonic radiation ceases.

● *ELECTROLYTIC POLISHING*

It is stated in a recent patent that the quality of electrolytic polishing at any moment during the process for a given metal and a given bath depends solely on the surface resistance of the anodic layer at that moment. Thus, by maintaining this resistance at a given value, the polishing process will then always be carried out with the same results. Moreover, it has been found that optimum polishing obtains with the surface resistance of the anodic layer maintained at a maximum or near that maximum. In order to achieve best possible process conditions, it is therefore proposed to make provision for constantly modifying the current intensity in order to maintain the resistance between the anodic layer and the cathode at its maximum value. In cases where the surface to be polished and the current density are relatively small, the control mechanism may be based upon measuring the resistance between workpiece and cathode; but where the surface to be polished is relatively large, the resistance between an auxiliary anode and the cathode is measured. Experience has shown that the evolution of the anodic layer on both anodes is the same and that the maximum of surface resistance of both layers occurs under the same conditions. Resistance measurement may also be carried out with the employment of alternating current. Obviously there exists a number of simple means by which actual control can be performed, since a fairly accurate adjustment of the current intensity is all that is required of the control gear.

● *THERMAL SHIELDS FOR ELECTRONIC VALVES*

In airborne electronic equipment, the shielding of thermionic valves falls into two categories, namely, the electric shielding necessary for the component to function as an integral part of an electronic circuit and the shielding to facilitate heat transfer. This latter type of shielding may be designed to perform the functions of an electrical shield as well. However, it is not always possible to modify a conventional electrical shield to provide adequate cooling for a given component. A recent study of various types of shields used for an amplifier valve of 18-watt heat dissipation has shown that the effect of enclosing the valve in a conventional polished aluminium shield led to an increase in the maximum valve surface temperature of approximately fifty per cent over that of the unshielded valve cooled by free convection at ground level barometric pressure. A conduction radiation shield was investigated under pressure conditions where free convection heat transfer is negligible. In this case, the heat dissipated from the valve is transmitted across the small air gap to the shield by radiation and gaseous conduction, and along the shield to the top by metallic conduction. Since the shield must dissipate all the heat gained from the valve, a thick shield offering a heat path of low thermal resistance will be conducive to relatively low temperature rises. It was found that the radiation-conduction type of shield regardless of altitude, and practically independent of it, can produce heat transfer coefficients comparable to free convection cooling at ground level pressure. The inability of conventional shields to facilitate heat transfer may be attributed to the thin shield wall, poor thermal contact with the chassis and the inability of the chassis to dissipate the heat gained from the shield.

● *PREHEATING FUEL CHARGE FOR OTTO CYCLE ENGINES*

A recent patent specification discloses a novel approach to the problem of operating internal combustion engines on the Otto cycle with any grade of motor oil from the light grades to the heavier ones. It is claimed that the new method will make it possible to build light-weight high-speed engines of reduced size, combining the simplicity of the Otto cycle engine with the low fuel consumption of the Diesel engine. It is not, of course, new to evaporate pump-injected fuel by means of special heating surfaces provided in the combustion space of the cylinder, these surfaces being heated by the heat produced in the preceding working stroke of the piston. Nor is it new to preheat the fuel in the front portion of the nozzle prior to its injection under the control of a needle valve. In contrast with these methods, the inventor claims a method of heating the liquid fuel immediately prior to injection by means of a heater which is so designed that the temperature of the fuel is raised above its vaporisation point at the pressure prevailing in the cylinder during injection. Introduction of the fuel at this temperature into the cylinder cavity will then be accompanied by a sudden drop in pressure which causes rapid evaporation of part of the fuel and consequent dispersion of the remainder. The heater to be used for this purpose consists of a tubular structure projecting into the cylinder cavity and provided with external circumferential ribs in order to increase the heat absorption on the side exposed to the hot combustion gases.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

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THE ENGINEERS' DIGEST
REVIEW OF WORLD ENGINEERING PROGRESS
VOL. XIV. No. 1. JANUARY, 1953

The British Aircraft Industry in 1952

THE British Aircraft Industry looks back on 1952 as a year in which Great Britain's position as a leading air power has been greatly strengthened. During recent months, when British jet airliners have been in regular daily service, more and more major overseas operators have come to this country to place orders for their new equipment. With the encouragement of the Government, which has now given them super-priority rating, the Industry has planned an unprecedented production programme for these jet and turboprop aircraft. Orders in hand for these aircraft alone are now approaching a value of £75 m. without spares, and a large proportion is for export.

At the same time, Service aircraft have been produced which show great advances in design and performance. Supersonic flight has been brought within practical reach and British designers have led the world with their bombers and fighters with the " new-look "—swept wings, deltas, and now the crescent wing.

This progress has been achieved against the background of rearmament. Early in 1952, the Prime Minister, Mr. Churchill, introduced the super-priority symbol to accelerate production of the key aircraft for the defence programme. Its purpose was to improve the supplies of labour, materials and machine tools. One of the most urgent tasks was to recruit skilled men, and, by super-priority and other measures, such as the allocation of houses, the labour force has risen from 180,000 in January to more than 200,000 at the year's end. It is still rising.

During this period the Government was making its re-assessment of the strategic position as it affected the defence programme. By the summer the outline of the new pattern was clear. The re-shaping of the air programme was to be based on the principle of concentrating more on quality than on numbers alone—on the quickest possible build-up of new aircraft and weapons of the latest type.

The " stretch-out " of the military programme meant that though production would rise less steeply than had been planned when the Korean war started, there would nonetheless be a call for sustained emphasis on the super-priority aircraft, with an overall continued increase in the output for defence. Thousands of skilled workers would still be required in the months to come for the defence programme—apart from those needed for civil production.

The great emphasis on production has meant no sacrifice of quality or inventiveness. The new wing shapes seen in flight for the first time during 1952 have been a remarkable proof of the continued versatility and genius of British designers. And while the new aircraft have been designed for high speed at great heights, designers have used their ingenuity to ensure good handling qualities at low speeds and low levels too—particularly at take-off and landing.

There have been continued advances in the thrust of existing jet engines. Powerful jets of new design include the twin-spool engine, giving great flexibility, and the by-pass type which promises excellent economy in operation, particularly for civil aircraft.

1952 has also seen the world's first helicopter with the twin-engined reliability which is fundamental to commercial helicopter operation. Likewise tests have begun on the first really large flying boat, a development which is a significant investment for the future.

Among the many revolutions in the technique of aircraft construction, there has been a significant move towards " designing for production." Its importance was emphasised by leading British designers during a recent conference on aircraft production.

Production engineers are now consulted to give practical advice in the early scheming stages of the aircraft so that production could proceed parallel with the prototype. Without their co-operation it would take four or five years to reach the production line from the prototype stage.

Little can be said at present of the Industry's work on guided missiles, though in this increasingly important field automatically-guided weapons have been produced which fly at speeds and heights far beyond the reach of existing fighters and bombers.

Although the Industry has throughout 1952 been busy with rearmament work, aviation exports have also been expanding steadily—a valuable contribution to the nation's security and solvency.

Already aircraft sales abroad are running at an annual rate of some £43m., to which must be added the " invisible export " of " know-how " in the form of licences to build British aircraft and engines abroad—notably in the United States and Europe.

For the future, a continued expansion of exports is expected. Military production will have been worked up to the point where some of the latest types can be provided for our allies and friends overseas. A steady supply of mainliners, cargo aircraft and small practical transports will flow abroad to link Great Britain with the Commonwealth and the free world.

U.S.A.

Hafnium Metal—Its Properties and Future

By J. L. EVERHART. (From *Materials & Methods*, Vol. 36, No. 5, November 1952, pp. 95-97, 4 illustrations.)

In recent years, a series of new metals has been produced in ductile form. Some, like titanium and zirconium, have reached the commercial stage, others are just leaving the laboratory. Among the latter is hafnium, a metal isolated and named only 30 years ago, a laboratory curiosity two years ago, and now in production by the iodide process in rods weighing up to 12 lb.

HAFNIUM and zirconium occur together in ores, the hafnium content of the ore generally ranging from 0·2 to 15 per cent of the zirconium content. Many of the properties of hafnium and zirconium are quite similar, and separation is difficult but can be accomplished by chemical means. After such separation, metallic hafnium is obtainable by the methods which are used for zirconium; that is, by the iodide and Kroll processes. Iodide hafnium contains less than 1 per cent zirconium, and the properties and characteristics discussed in the following sections were determined on this material.

Like zirconium, hafnium combines readily with all but the noble gases. Oxygen dissolves in the metal and, in sufficient quantities, makes it permanently brittle. Since hafnium is so reactive, no deoxidisers are known and careful melting practice is necessary to obtain ductile material. The crystal bar obtained in the iodide process can be melted in an arc furnace under argon to obtain massive hafnium suitable for further working. After the metal has been obtained in massive form, the rate of oxidation is sufficiently low to permit hot working in air. By a combination of hot and cold working procedures, the metal has been produced in the form of sheet and wire.

Some of the properties of iodide hafnium are given in Table I, which includes also properties of zirconium and titanium for comparison.

TABLE I. COMPARATIVE PROPERTIES OF HAFNIUM, ZIRCONIUM AND TITANIUM.

	Hafnium	Zirconium	Titanium
Density, lb/cu in.	0·47	0·24	0·16
Melting point, °F	3590	3355	3140
Therm. cond., BTU/sq ft/ft/hr/°F at 212° F	——	9·6	8·1
Coeff. of exp. per °F at 70° F	$3·4 \times 10^{-6}$	$3·1 \times 10^{-6}$	$5·0 \times 10^{-6}$
Spec. Ht., BTU/lb/°F	0·035	0·069	0·13
Elect. Resist., microhm-cm	30	40	60
Elect. Cond., % I.A.C.S.	5·7	4·3	3·1
Mod. of Elast. (tension), psi	20,000,000	14,000,000	15,000,000

Little information is available on the mechanical properties of hafnium. Crystal bar has a hardness, as deposited, of about Rockwell B78. After arc melting and annealing, the material has about the same hardness. In a material which had been cold-worked to 60 per cent reduction, the hardness increases to B102.

The oxidation resistance is important for determining suitable conditions for hot working and possibly for elevated temperature service. Tests made in still air showed that at 1380° F hafnium and zirconium oxidised at approximately the same rate, but at 1650° F the rate of oxidation of hafnium was only about half that of zirconium.

The corrosion resistance of the new metal is still under investigation. In general, in its resistance to mineral acids, hafnium more nearly resembles titanium than zirconium. However, all three materials are approximately equally resistant to 10 per cent sulphuric acid, while hafnium is superior to the others in resistance to a one-to-one mixture of hydrochloric and sulphuric acids. All three metals show excellent resistance to a 20 per cent sodium chloride solution, although hafnium is the least resistant of the group. In its resistance to 50 per cent sodium hydroxide, hafnium is superior to titanium but inferior to zirconium, which shows no weight loss under the conditions of the test. These initial results indicate that hafnium has promising characteristics for use in corrosive environments although probably only in specialised applications, since the metal will more than likely be available only in limited quantities.

Hafnium can be hot-worked in air at 1650° F without protection, and it should be possible to hot-forge the metal by procedures similar to those employed with zirconium; that is, by using light blows of the hammer to prevent cracking.

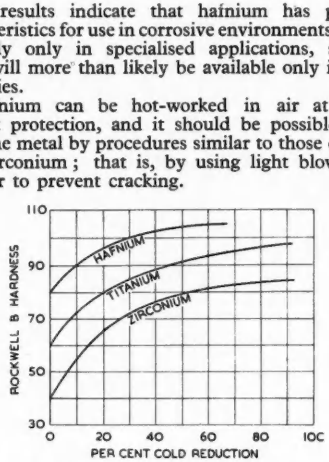


Fig. 1. **Effect of cold work on the hardness of iodide hafnium, zirconium and titanium.**

An indication of the relative work-hardening of hafnium, zirconium and titanium can be obtained from Fig. 1. Although hafnium is harder and somewhat more difficult to work than zirconium, cold-working to a maximum reduction of 30 per cent between anneals is possible. No information on the cold forming characteristics is available, but it is probable that the metal can be bent, deep-drawn and formed by slight modifications of the methods used for zirconium. Such procedures would have to be less drastic than those used for zirconium to compensate for the fact that hafnium is a harder material. The crystal structure of hafnium is similar to that of magnesium. Metals with this structure are less easily worked than metals having structures like those of iron or copper. As in the case of zirconium, the workability of hafnium should be improved by raising the temperature to about 400° F. In the limited machining operations which have been performed on hafnium, tooling similar to that used for machining 18/8 stainless steel has been satisfactory.

The crystal structure of hafnium changes at 2400° F from hexagonal close packed (the room temperature modification) to body centred cubic. This transformation is similar to that which occurs in zirconium at 1580° F and in titanium at 1625° F. Thus, the room temperature modification of hafnium is stable to much higher temperatures than that of zirconium and titanium.

Cold-worked hafnium can be completely recrystallised by heating to 1435° F. Annealing should be carried out at a somewhat higher temperature, for example, 1550° F. The rate at which oxygen is absorbed is sufficiently low to permit annealing operations on heavy sections to be carried out in air. For very light sections, annealing in a protective atmosphere is preferable.

Hafnium can be joined by methods similar to those used for zirconium. Thus, welding can be done by arc or flash-butt procedures in inert atmospheres.

(*Concluded on page* 8)

Stresses in Circular-Patch Weld-Test Specimens

By A. V. Levy and H. E. Kennedy. (From *The Welding Journal*, Vol. 31, No. 9, September 1952, pp. 402s-405s, 6 illustrations.)

The circular-patch type of weld-test specimen promises to supply the restraint needed to produce combined stresses similar to those found in service. A comprehensive study of the stresses of a circular-patch weld test should therefore be of value to the present and future users of this test.

This investigation was concerned with a study of the residual stresses in specimens of various plate sizes and patch sizes. Most uses of the test to date have been restricted to specimens which are too large to be handled by one person. The use of smaller specimens is preferred, as long as they can duplicate the restraint provided by the larger specimens. In this work, the patch size was varied from 3 to 8 in. in diameter. The plates employed varied from 9 to 18 sq. in. The patches were cut from the plate and scarfed by flame cutting. Unionmelt welds backed up with hand welds were used to join the patch to the plate. The magnitude of the residual stresses induced in the plates by the welding were later determined with SR-4 strain gauges glued to the plate. The stresses were relieved by cutting the gauge sections out of the plate with a saw.

The specimens were Unionmelt welded to avoid the variables introduced by hand welding. A hand back-up weld was used before Unionmelt welding. The hand weld provided approximately 40 per cent of the total weld metal deposited. The efiect of the hand weld was almost completely removed by the heat and depth of penetration of the machine weld.

Procedure.

The specimens used were flame cut from a 22- by 7-ft by 1-in. hot-rolled mild steel plate. The percentage chemical composition of this steel was : 0·24 carbon, 0·50 manganese, 0·07 silicon, 0·05 chromium, 0·08 nickel, 0·07 copper, 0·04 aluminium, 0·05 sulphur and 0·45 phosphorus. The circular patches were flame-cut by rotating the specimens on a variable-speed turntable under a stationary torch. For the hand welding, the plates were pre-heated to 300° F and tack welded, the back-up weld being completed subsequently. A single hand pass was laid in the top weld groove prior to completing the final weld by the Unionmelt process.

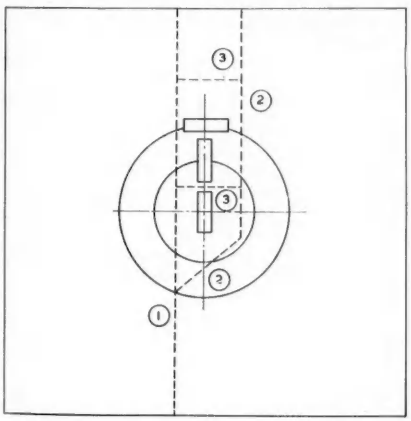


Fig. 1. **Sketch of test specimen showing location of strain gauges and pattern of saw cuts.**

The welding speed was 10 ipm. Operating conditions were : current = 950 A ; open-circuit voltage = 36 V ; closed circuit = 32 V ; reverse polarity was used.

SR-4 resistance wire strain gauges were used to determine residual stresses. The plates were ground flat on both sides along a radius perpendicular to the rolling direction. The gauges were mounted to the plate, as shown in Fig. 1.

Readings of the gauges were taken before and after cutting to determine the elastic strains.

Results

Stresses were computed from the measured strains by conventional combined stress analysis. The residual stress level of the test specimens was most accurately determined at the centre of the patch. The strains from the top and bottom gauges at all positions were averaged to get the strain used in the stress calculations. Plots of the resultant residual stresses at the centre *versus* the patch diameter are presented in Fig. 2. The

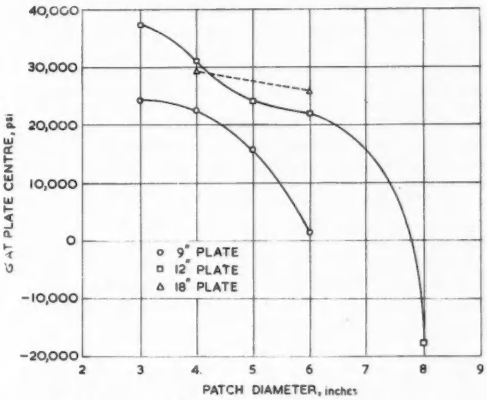


Fig. 2. **Stress of plate centre *vs.* patch diameter.**

residual tensile stress at the plate centre is of the order of the yield stress for the smaller size patches in the 12- and 18-in. plates and decreases with an increase in patch size. The compression stress at the centre of the 8-in. patch in a 12-in. plate reverses the trend of tension stress in the patch. The stress level of the 9-in. plate is considerably below that of the two larger-size plates. For the small patch sizes, the stress level of the 12-in. plates exceeds that of the 18-in. plates. As the patch size increases, the stress level of the 18-in. plates begins to exceed that of both the smaller size plates. The magnitude of the residual stress for the smallest patch sizes in the 12-in. plate exceeds or equals the yield stress of the untreated, hot-rolled plate (longitudinal 34,700 psi, transverse 31,600 psi).

The maximum circumferential stress in the weld zone *versus* patch diameter is plotted in Fig. 3. The strains were determined by strain gauges placed so that the gauge section of a radially placed gauge and a circumferentially placed gauge were on the weld and adjoining area. The strains from matching gauges on the underside of the plate were averaged with the readings from the top gauges. The weld zone was approximately 2 in.

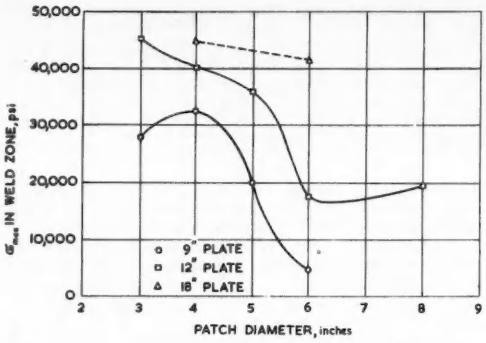


Fig. 3. **Maximum circumferential stress in weld zone *vs.* patch diameter.**

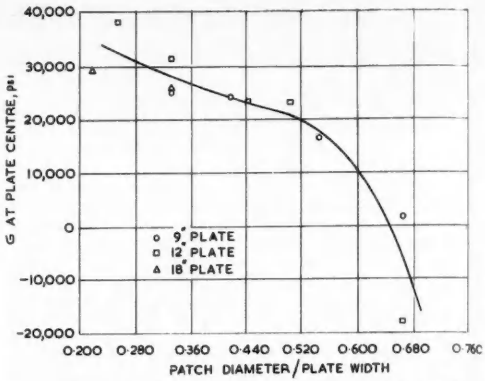


Fig. 4. **Stress at plate centre *vs.* patch diameter/plate width.**

wide. It was found that the circumferential stress exceeded the radial stress. The magnitude of residual stress was greatest for the 12-in. plate. The smallest diameter patches resulted in residual stresses considerably above the uni-axial yield stress of the untreated plate. The curve for the 18-in. plate was determined from only two specimens and was therefore drawn as a straight line. The stress level of the 12-in. plate is greater than that of the 9-in. plate and is of the same order of magnitude as the 18-in. plate at the smallest patch diameters.

The comparison of the plate sizes is better interpreted from a plot of stress against the ratio of the patch size to the plate size. Figure 4 shows that the effect of increasing the patch size is to decrease the residual stress level. This effect follows a curved line relationship which is the same for all plate sizes. For the smaller diameter patches, the stress level attained in the 12-in. plate exceeds the degree of residual stress present in the 9- and 18-in. plates.

The maximum circumferential stress in the weld zone varies with the ratio of patch size to plate size. The stress level decreases with an increase in the ratio. The smaller volume of metal in the 9-in. square plate cannot provide the restraint necessary to induce residual stresses of yield stress magnitude in the weld zone.

Discussion

The data reported herein indicate that residual tension stresses are present at the centre and in the weld zone of circular-patch weld-test specimens. The magnitude of these stresses is of the order of the yield stress of the plate material when the patch diameter to plate width ratio is in the range 0·2 to 0·3, and is lower for specimens of larger ratio. The region of residual tension stresses extended from the centre of the plate outward beyond the weld zone. The tensile stresses were measured both in a radial direction and in a circumferential direction. At the centre, symmetry resulted in equal stress magnitudes in all directions. Away from the plate centre, the circumferential stress exceeded the radial stress. To balance the forces circumferential compression stresses occur at the plate's periphery.

The weld-zone is, therefore, subjected to residual bi-axial tension stresses. High residual tension stresses in weld tests presumably provide the most critical condition for evaluating the strength of the weld and the surrounding heat-affected zone. Bi-axial stresses of the order of the yield stress, as obtained in this circular patch test, fulfill the conditions necessary for a severe weldability test.

As the patch diameter is increased in a plate of given size, a diameter is reached where the pattern of residual stresses in the plate is changed. The centre stress changes from tension to compression.

The effect of varying the patch size is to change the magnitude of the residual stress, which continually decreases with increasing patch diameter. However, the decrease is not linear.

The effect of varying the plate size is significant in that it does not have a substantial effect on the residual stresses induced, provided that the patch diameter to plate width ratio is the same and the plate size exceeds 9 in. The use of 12-in. wide plate thus appears to be satisfactory for circular-patch weld-test specimens of 1 in. thickness.

In the past, the use of circular-patch weld tests depended upon the discovery of cracks in the weld or adjacent zone as the criteria for acceptable performance of the joint. Cross-sections of the 3 in. dia. and 4-in. dia. patches from both the 12-in. wide and 18-in. wide plates were examined for cracks, but none was found. However, the steel used was a ductile mild steel not susceptible to underbead cracking.

The altered metallurgical structure in the weld and heat-affected zone increased the yield stress of the base metal over the 32,000 psi yield stress of the as-received, hot-rolled plate. For this reason, values of residual stress somewhat above 40,000 psi were obtained in the weld and heat-affected zone of the plates with small diameter patches.

The residual stress in the hot-rolled, unwelded plate and the stresses introduced by the flame cutting operations were determined in a 12-in. wide plate, from which a 4-in. dia. patch had been cut. The results indicate that the magnitude of these stresses could be, at the most, only a minor contributing factor to the resultant stress after welding. The effective residual stress pattern of the unwelded test plate is severely altered by the effect of the thermal gradients created during the welding operation.

HAFNIUM METAL—ITS PROPERTIES AND FUTURE

(*Concluded from page* 6)

However, the weld area must be completely shielded if ductile welds are to be produced.

As occurs with the introduction of each new metal, suitable applications appear only after its characteristics have been fully evaluated. Up to the present time, no commercial applications have been developed for hafnium except in the atomic energy programme, where specific applications have not been revealed. It has been suggested for use in electronic tubes ; and alloys of hafnium containing copper, silver and nickel have been produced by powder metallurgy methods.

Working Stresses and Working Strength of Spur Gears

By A. THUM and K. RICHARD. (From *Schweizer Archiv*, Vol. 18, No. 10, October 1952, pp. 309-321, 19 illustrations.)

Stresses in spur gears are so complex that only tests under working conditions can give indications of the strength, toughness, and wear resistance of gears, and of the influence of material, heat treatment, tooth shape and loading on these properties. There exists at present a tendency towards standardisation of certain test methods. Published testing experience may serve as a basis for a summary of current knowledge on gear strength and for a critical appreciation of the testing methods.

A. STRENGTH REQUIREMENTS, CHOICE AND TREATMENT OF MATERIALS.

In the majority of applications of gears, strength requirements play no part and gears may be made of cast iron, mild steel, brass, plastics, or wood; surface smoothness and profile accuracy are also unimportant. However, in vehicle and aircraft production and in some general engineering applications, gears are so highly loaded that special steels must be used, which must be heat treated and carefully machined. The following basic considerations on gear strength mainly apply to this last group. Gear teeth may fail by fracture, by wear at the root or tip, by pitting near the pitch zone, or by splintering at the end faces of gear change teeth. In order to prevent such failures, gears must, firstly, resist wear by abrasion and by *contact pressure*, i.e., the tooth surfaces must be hardened. Secondly, they must *resist repeated bending* across the root of the tooth. Since the fatigue limit increases with hardness, the hardness of the material at the root must be high, but not so high as to produce notch sensitivity. Thirdly, they must be *shock resistant*, and capable of absorbing large shock energies purely elastically, since any permanent plastic deformations would affect the accuracy of the tooth profile and thus lead to even heavier shocks. These requirements are difficult to reconcile, and the unfavourable stress concentrations at the root of the teeth increase the difficulties.

Strength and toughness of the gear may be increased by drop forging the blank instead of machining it from rolled bar; the fibrous grain structure due to impurities in the rolled material follows the contours of the drop forging, but is cut transversely and weakened by machining from bar. Accurate profile machining and hardening with least distortion, or grinding after heat treatment, reduce vibratory stresses in the running of gears; a large root radius reduces dangerous stress concentrations. Correct choice of material and heat treatment is essential for high-quality gears. *Case hardening steels* (Table I) are carburised in powder or in salt baths, so that the skin acquires a higher carbon content (usually up to 0·9 per cent C in Germany, 1·2 to 1·4 per cent C in U.S.A.) than the core. The gears are then quenched, or double-quenched, separately for core and skin in very highly stressed applications; the skin hardness should be 727 to 836 Vickers pyramid hardness. According to experience the skin depth should be 1/10 to 1/5 of the gear module, or 1/80 to 1/40 of the circular pitch, but above 0·02 in. if the hardened teeth are ground. The metallographic structure of the skin (martensite) occupies a greater volume than that of the core so that the residual compression stresses strengthen the skin against fatigue and notch effects. Alloy steels may also be nitrided in an atmosphere of ammonia; the resulting extremely hard surface skin (1100 Vickers), however, is so thin that the teeth cannot be ground. Although the normal heat treatment of *through-hardening steels* with a high carbon content would lead to unfavourably brittle teeth, there exist some special heat treatments which combine a high

TABLE I. COMPOSITION OF CASE-HARDENING AND FULLY HARDENING GEAR STEELS (GERMAN SPECIFICATION).

Steel	C	Si	Mn	Ni	Cr	Mo	V
	Case-hardening						
C 15	0·11–0·18	0·15–0·40	0·2–0·4				
C 22	0·29–0·25	0·15–0·40	0·2–0·4				
13 Ni Cr 10	0·10–0·17	0·35 max	0·5 max	2·25–2·75	0·55–0·95		
13 Ni Cr 14	0·10–0·17	0·35 max	0·5 max	3·25–3·75	0·55–0·95		
13 Ni Cr 18	0·10–0·17	0·35 max	0·5 max	4·25–4·75	0·9–1·3		
15 Cr 3	0·12–0·18	0·4 max	0·4–0·6		0·5–0·8		
16 Mn Cr 5	0·14–0·19	0·4 max	1·0–1·3		0·8–1·1		
20 Mn Cr 5	0·17–0·22	0·4 max	1·1–1·4		1·0–1·3		
22 Mn Cr 6	0·20–0·25	0·4 max	1·3–1·6		1·2–1·5		
15 Cr Mo 5	0·13–0·17	0·35 max	0·8–1·1		1·0–1·3	0·2–0·3	
20 Cr Mo 5	0·18–0·23	0·35 max	0·9–1·2		1·1–1·4	0·2–0·3	
	Fully hardening						
C 35	0·32–0·40	0·3–0·5	0·4–0·6				
C 45	0·42–0·50	0·3–0·5	0·45–0·65				
C 60	0·57–0·65	0·3–0·5	0·5–0·7				
28 Ni Cr 10	0·25–0·32	0·35 max	0·4–0·8	2·25–2·75	0·55–0·95		
35 Ni Cr 10	0·32–0·40	0·35 max	0·4–0·8	2·25–2·75	0·55–0·95		
22 Ni Cr 14	0·20–0·27	0·35 max	0·4–0·8	3·25–3·75	0·55–0·95		
30 Ni Cr 14	0·27–0·35	0·35 max	0·4–0·8	3·25–3·75	0·55–0·95		
35 Ni Cr 18	0·30–0·40	0·35 max	0·4–0·8	4·25–4·75	1·1–1·5		
33 Cr 4	0·30–0·37	0·35 max	0·5–0·8		0·9–1·2		
32 Cr Mo 4	0·30–0·37	0·35 max	0·5–0·8		0·9–1·2	0·15–0·25	
42 Cr Mo 4	0·38–0·45	0·35 max	0·5–0·8		0·9–1·2	0·15–0·25	
42 Cr Mo 7	0·38–0·45	0·35 max	0·5–0·8		0·9–1·2	0·3–0·4	
37 Mn Si 5	0·33–0·45	1·1–1·4	1·1–1·4				
50 Cr V 4	0·47–0·55	0·4 max	0·7–1·0		0·9–1·2		0·10–0·18

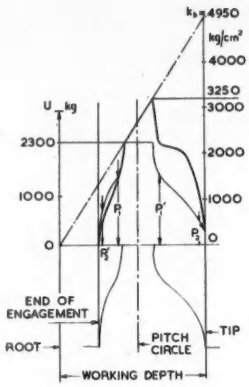


Fig. 1. **Change of peripheral load U on tooth flanks and of bending stress k_b at the root of the tooth during the period of engagement.**[1]

23 teeth, module 15 (circular pitch 1·85), pressure angle 20 degrees, tooth width 0·4 in.

surface hardness with a relatively soft core. Treatment in a cyanide bath slightly carburises and nitrides the skin so that, after quenching, the core remains softer than the surface; the small depth of the hard, wear-resistant skin permits lapping, but not grinding, of the tooth flanks. With dip, flame, or induction hardening processes, only the skin is heated to quenching temperature and hardened by immediate quenching. The speed and duration of heating controls the depth of hardening and the hardness gradient. This method has the disadvantage that surface heating re-anneals the previously hardened and tempered material, so that a narrow annealed zone of lower strength remains between the pre-treated core and the subsequently hardened skin. The distortion, however, is smaller than with case-hardened or cyanide-hardened gears. The whole gear may be heated and hardened in a ring-shaped flame or induction equipment; the tooth tips are then hardened more intensively than the roots. With large teeth, every tooth or tooth gap may be treated separately by specially arranged burners, or induction coils, with quenching jets; here, the hardness distribution is similar to that of a cyanide-hardened gear. Finally, the depth of hardening may be controlled by the metallurgical composition of the steel, e.g., by varying contents of manganese or vanadium; closely controlled alloys specially selected for the required tooth pitch then ensure a slightly softer core.

B. TOOTH LOADS AND STRESSES.

During the action of the tooth, the point of loading travels from the root to the tip or vice-versa. The load increases from zero to a maximum occurring when only one pair of teeth engages, and drops again to zero (Fig. 1). This non-sinusoidal cycle is repeated once during every revolution of the gear and constitutes a fatigue loading fluctuating between zero and maximum if the tooth force always acts on the same side. As the tooth flanks wear, the load distribution over the tooth face changes slightly. The total tooth load P (Fig. 2) produces bending, compression and shear stresses at the root. Generally, the tension stress σ_b due to bending by the peripheral component U is taken as the critical stress for hardened gears and the greater compression stress $\sigma_c = \sigma_b + \sigma_d$ due to U and R as critical for unhardened gears.[2] The radial component R reduces the calculated tension stress σ_b by direct compression σ_d, and its effect increases with decreasing ratio x/b, i.e., with increasing pressure angle and tooth correction. Comparison with a cantilever shape of constant bending strength shows that the involute tooth is weakest at the root and that the tension stress increases towards the root (Fig. 3); furthermore, the notch effect of the root radius considerably raises the nominal stress at the root (Fig. 4).[3-5] Nevertheless, compression usually remains

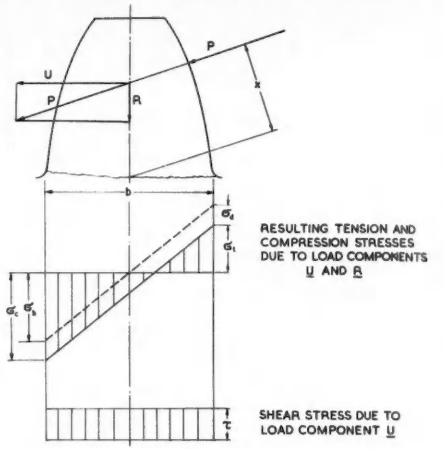
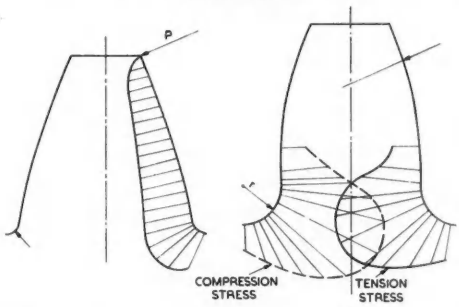


Fig. 2. **Stresses at the root of the tooth caused by a normal tooth load P.**



Figs. 3 and 4. **Tension stresses along the whole tooth surface and notch effect at the root of the tooth, determined photo-elastically.**[4]

2 D.P., root radius 0·147 in., pressure angle 14·5 degrees (Brown & Sharpe), pitch diameter 12 in., load 1 lb., ratio x/b (Fig. 2) = 0·776.

still higher than tension (Fig. 5). The stress concentration factor α_K (Fig. 6) decreases towards a limiting value as the bending lever arm lengthens and the accompanying transverse shear stress τ decreases. Especially when the effective overlap, e.g., of ground teeth, displaces the maximum bending force towards the root, this effect of transverse shear cannot be neglected. In fact, α_K proves to be independent of the load lever arm when the nominal tension stress at the root is taken as

$$\sigma_v = \sqrt{(\sigma_b - \sigma_d)^2 + (a\,\tau)^2} \quad \ldots\ldots \quad \ldots\ldots \quad (1)$$

where a = 2·0 to 2·9 according to tooth form.[5] In surface-hardened gears, the maximum tension skin stress is diminished by the residual compression stresses. On the other hand, non-parallel gear axes and quench distortions of unground teeth appreciably increase the stress maximum.

The more accurate the tooth shape and the smaller the backlash, the more the elastic deformation of the teeth must be considered and limited by tooth correction. Fig. 7 illustrates the tip deflection due to a loading as shown in Fig. 1.[1] This deflection would produce a

shock load at the start of engagement of the subsequent tooth (entry shock), and the tip thickness is therefore usually reduced by about 1/8000 of the circular pitch per tooth side. Rough working conditions or resonance vibrations produce "external" machining errors in pitch, profile, or concentricity, "internal" additional dynamic loads leading to peak stresses. These peaks can hardly be calculated or even measured[3]; they must be estimated in amplitude and frequency and taken into account by safety factors. If the peripheral speed is high, the dynamic stresses may be so high that only a small effective torque can be transmitted. The dynamic forces depend on the effective inertia mass and the elasticity of the teeth; long narrow teeth reduce the stress peaks by the energy of deformation they absorb, but unless wear or a special shape provide sufficient tip clearance to prevent entry shocks, the dynamic stresses are still further increased by the amount of this shock.

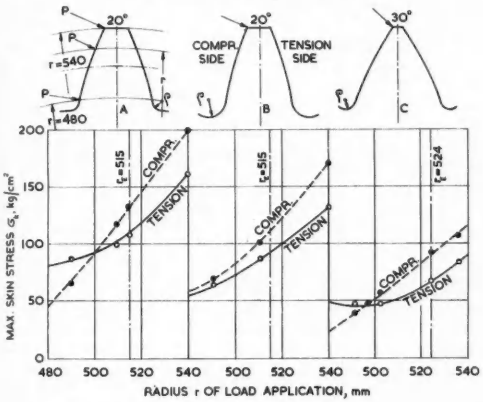


Fig. 5. **Maximum compression and tension stresses at root of tooth as a function of the load lever arm for different tooth forms, determined photo-elastically.**[5]

Module 30 (circular pitch 3·7), 34 teeth, 0·4 in. width, 220 lb tooth load.

Tooth Form A: 20 deg. involute with root radius 0·2 module (0·236 in.).

Tooth Form B: 20 deg. involute with semi-circular root.
Tooth Form C: 30 deg. involute with semi-circular root.

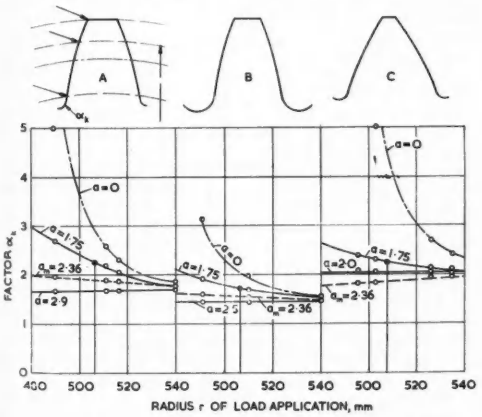


Fig. 6. **Shape factor α_K as a function of the load lever arm for different tooth forms.**[5]

$\alpha_k = \sigma_k/\sigma_v$, where σ_k has been taken from Fig. 5 and σ_v calculated from eq. (1).

(The values of α_K for the different tooth forms are not strictly comparable since the root radii differ).

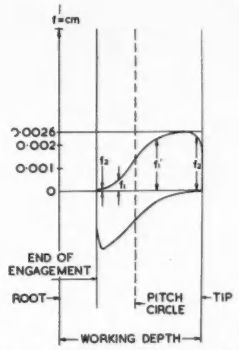


Fig. 7. **Deflection of single tooth and pair of teeth during the period of engagement.**[1]

Peripheral component of tooth load 2·3 tons, 23 teeth, module 15 (circular pitch 1·85), pressure angle 20 degrees, tooth width 0·4 in.

Attempts to calculate the influence of speed or profile errors on the dynamic additional stresses have been made.[6]

Too high a contact pressure between teeth leads to pitting. While abrasion wear usually occurs under unfavourable lubricating conditions at points of maximum relative sliding, pitting occurs at points of little relative sliding and is believed to be due to excessive shear fatigue stresses. Cracks leading to breaking out of particles start below the surface at points of greatest shear stresses under contact pressure between curved surfaces.[7] The modulus of elasticity, curvature at the point of contact, state of the surface, work-hardening of the flank, and lubricating conditions, all influence the appearance of pitting. With well lubricated high-speed gears, pitting takes place near the pitch circle where the relative curvature is greatest and the contact load is usually carried by one pair of teeth only.[8] Pitting has been observed to start at points where overlap ceases on the pinion side,[9] or also generally at points just inside the pitch circle.[10] Relative sliding produces here tangential tension stresses, the so-called "negative slip," and slip values of 20 to 30 per cent have been found to be the most dangerous.[11] Pitting does not take place in the absence of lubricants. In fact, contact pressure changes the molecular structure of the oil film, and the subsequent separation of the contacting surfaces subjects the oil film to high tension or shear stresses which, if repeated, will destroy the tooth surface by fatigue.[12] Under favourable conditions, initial pitting of soft teeth may be stopped by work-hardening, but extensive pitting will soon destroy the whole tooth flank or lead to fracture. The contact pressure can be calculated from Hertz's formula.

C. The Limiting Strength of Teeth.

The limiting stress for bending of gear teeth is the proof stress for which the deformation reaches the maximum allowable value; with brittle materials and under fatigue conditions, it may coincide with the fracturing stress. Since the elastic deflection alone may already cause entry shocks, the total, i.e., elastic plus permanent, deformation must always be limited to less than the designed backlash, whether continuous or shock loads are applied singly or repeatedly. The gear steels respond differently to these different loading conditions and the limiting stress will vary correspondingly. The fracturing stress varies still more widely for the different mechanisms of destruction. A hard core leads to brittle fracture without any plastic deformation (Fig. 8 (left)). Unhardened soft teeth deflect permanently already at low loads; the subsequent stress redistribution and work-hardening, however, result in very high fracturing loads which cannot be utilised

since the permanent deflection soon exceeds the permissible limit. The ideal gear material should have a high elastic load limit with a small plastic range as a safety margin. The tooth load-deflection curves of Fig. 8 are examples of two practical heat-treated steels, but should not be regarded as typical for case-hardened and fully hardened teeth. Since there is no pronounced yield stress, the maximum allowable stress should be fixed by limiting the total deflection, say, at the pitch circle, to 0·2, 0·5, or 1·0 per cent of the tooth gap, according to the required profile accuracy and backlash. This stress would permit comparison of independent test results, while the fracturing stress given in many publications does not sufficiently characterise the relative behaviour of different gear materials.

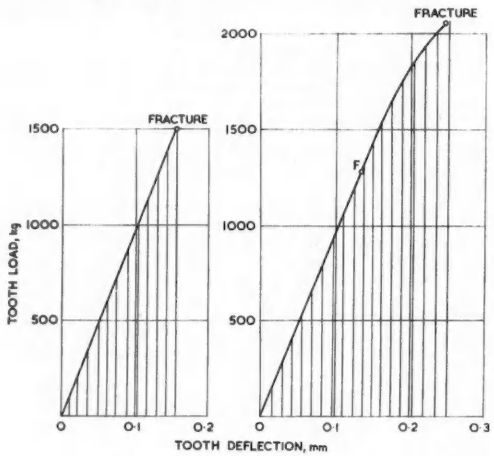


Fig. 8. **Load-deflection curves for case-hardening steel 20 Mn Cr 5 (left) and cyanide-hardened through-hardening steel 32 Cr Mo 4 (right).**
27 teeth, module 3 (8·5 D.P.), tooth width 0·4 in. thickness of case about 0·03 in.

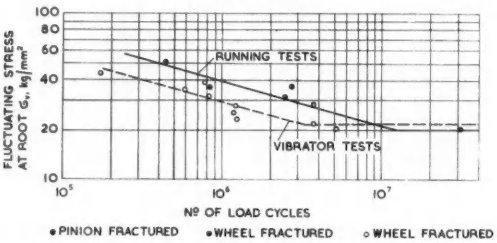


Fig. 9. **Influence of type of testing on the short-time and fatigue strength of a tooth.**[5]
Gears of 15 Cr 3 case-hardening steel, hardened and tempered, module 3 (8·5 D.P.), 34 teeth (vibrator) and 27/34 teeth (running test), tooth width 0·4 in., 20 degrees involute.

Static bending tests with measurement of the tooth deflection are quick and simple and supply valuable criteria for the material and its heat treatment, but do not correspond to working conditions. The fluctuating working loads may be reproduced by running tests of complete gears or by the simpler and cheaper pulsating load tests on single teeth. Since the usually sinusoidal load changes of the vibrator do not correspond to the working load changes, e.g., of Fig. 1, the results of these two types of tests will slightly differ for comparable tooth forms (Fig. 9).[5] In short-time tests, the comparatively high testing loads lead to considerable deflections which, in running tests, reduce the single tooth load by increased overlap; the vibrator test exerts a constant load on one tooth and is thus more severe.

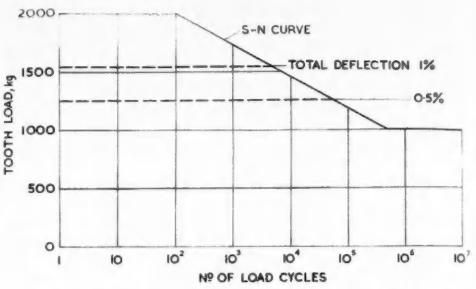


Fig. 10. **Limit of maximum tooth load due to the permissible tooth deflection.**
Fully hardening 32 Cr Mo 4 steel, 27 teeth, module 3 (8·5 D.P.), tooth width 0·4 in.

Under fatigue limit conditions, however, tooth errors and superimposed vibrations make the running test more severe. In vibrator tests, the point of load application is stationary, and if it is too near the root, the influence of the shear stresses reduces the tooth strength still further. Since the permissible deflection might be exceeded under short-time conditions, only the lower part of the *S-N* fatigue curve with its smaller deflections should be used (Fig. 10). Under shock load conditions, no permanent deformation at all is permissible, as it would be used up after a few shocks and would not be available for unforeseen shock peaks. Hence, the measurement of the total, i.e., elastic plus plastic, energy of deformation under single or repeated shocks does not provide useful data unless the elastic and plastic parts can be separated. Unhardened gears, for instance, have a far higher total energy of deformation than hardened gears, yet are unsuitable for shock loads. Moreover, materials differ in their resistance to hard infrequent shocks and to slighter, but more frequent, shocks, so that knowledge of an *S-N* curve under shock conditions with simultaneous consideration of the elastic deformation limit is as important as for normal running. It is proposed to discuss this problem in a later paper.

The resistance against sliding wear depends largely on lubricating conditions and cannot be regarded as a property of the steel only. Moreover, since tooth roots and tips are worn first, the resulting increased overlap of teeth will lead to a reduction of the load, the greatest part of which will then be carried by a region of less relative sliding near the pitch circle. A fatigue limit may be established for rolling pressures leading to pitting if the curvatures of the tooth flanks and the surface hardness are known. However, this limit also depends on the viscosity of the lubricant[10, 12]). Positive slip, in turn, increases resistance to pitting.[13] If tooth tips and roots are worn after long service, pitting may still start due to the load concentration near the pitch circle. A unique coefficient of resistance of the steel to pitting is, therefore, an impossibility. Finally, gear changes produce unpredictable shock loads resulting in wear of the tooth edges.[14] Here, only comparative tests of new materials with used proven steels can lead to improvements.

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Radioactive Static Electricity Eliminators

By J. D. GRAVES. (From *Metal Progress*, Vol. 62, No. 5, November 1952, pp. 94-96, 2 illustrations.)

THE formation of static electricity may constitute a serious problem in many industrial processes. Moving non-conducting materials, such as paper, cellophane, dusts and rayon, create and store static electricity at points of friction—for example, where paper leaves a roll. Sparks from static charges may ignite inflammable dusts, metal powders, gases or vapours. Statically charged materials tend to stick together, to repel each other, or to attract foreign materials, and thus interfere with production.

The use of radioactive static eliminators is not a panacea for all such problems, but their advantages ensure wider adoption as practical experience is acquired. The expected availability of large quantities of relatively low-cost radioactive materials would extend the range of application.

Radioactive static eliminators emit alpha, beta, or gamma rays, or a combination of them. These radiations ionise the air or gas surrounding the radioactive source. Ionised gas is a conductor of static electricity and serves as the invisible mechanism which carries the trouble-making static electricity harmlessly away. Figure 1 shows how the eliminator functions, using paper coming from a belt or roll as an example. Friction at the point where the paper leaves the belt causes it to become electrically charged with respect to the belt. As a result, the belt and paper may attract each other and become difficult to separate. The effect of the radioactive static eliminator is to ionise the air where the paper and belt part. The positive air ions will flow to the paper and the negative air ions to the belt, neutralising both and eliminating the attractive forces.

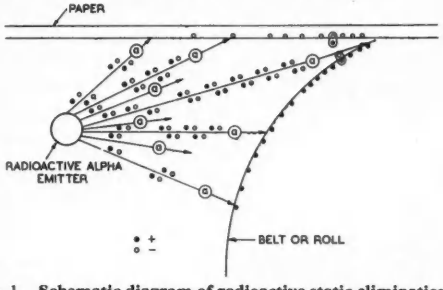

Fig. 1. **Schematic diagram of radioactive static elimination in a paper mill. Alpha particles, α, produce charged ions which are attracted to and neutralise the opposite static charges on the paper and roll.**

Alpha particles (double ionised helium atoms) are very heavy and will ionise air only a short distance away from the source. Therefore, alpha emitters must be placed within a few inches of the spot where the static electricity is to be bled off. Where it is desirable to eliminate static electricity over several small areas, such as in the paper-belt separation, alpha-emitting eliminators are effective. The advantage of alpha particles is their high ionising ability, allowing use of small quantities of radioactive material.

Beta particles are 7000 times lighter than alpha particles and ionise air out to a few feet from the source of radiation. Each beta particle will produce the same total number of ions as each alpha particle of the same energy, but a beta source will distribute the ions through a much greater volume of gas than an alpha source. The number of ions per unit volume of air is correspondingly smaller with beta radiation. Consequently, much more radioactive material would be required to eliminate static electricity from the paper-belt separation process with beta particles. From this standpoint of energy utilisation, beta rays are efficient for static elimination only when relatively large surfaces must be discharged.

Gamma-ray eliminators are in the realm of possibility, with large sources of such rays in prospect. Their utilisation, however, would be limited to processes where it is necessary to ionise large volumes of air in an uninhabited or heavily shielded area. Gamma radiation could be utilised to advantage where the charge is drained through liquids or solids.

In a commercial static eliminator consisting only of a bar of metal holding a foil of radio-active material, the ionising radiation is directed toward the statically charged material and shielded in other directions. Radium, radium-D, or polonium may be the radioactive material. Radium emits alpha, beta, and gamma rays; radium-D emits alpha and beta rays; and polonium emits alpha particles only.

If the presence of beta and gamma radiation is permissible, radium has the advantage of a 1600-year half-life. Where gamma radiation is not permissible, radium-D may be used. It has a half-life of 22 years, but is not practical as a beta-emitting eliminator because of its cost. Where neither beta nor gamma radiation is permissible, polonium may be used. This has a half-life of only 138 days, requiring periodic replacement.

With the exception of cobalt, all of the radioactive materials for static eliminators, now and in the foreseeable future, are rare and have little use other than for their radio-activity.

Radioactive static eliminators are completely safe if properly constructed, installed, and used. On the other hand, they can be serious hazards if misapplied. The responsibility for construction and installation must fall to those fully cognisant of the properties and potential hazards of radioactive materials; they must recognise and provide safeguards for inexperienced operating personnel. The consumer should have the eliminator and the surrounding equipment checked periodically by the supplier or a radiation detection service to assure its safe continuance—at least until the particular device is proved safe in its environment.

A great deal of care must be exercised in construction of the equipment. The radioactive material should be completely enclosed so that no radiation becomes unshielded and no portions of the material can be scraped off or will scale off to disperse where it can be inhaled or ingested.

Pure alpha emitters will cause no damage outside of the body since they cannot penetrate the skin. If they are inhaled, ingested, or absorbed into the body, they will deposit and cause tissue destruction. The alpha-emitting material is generally impregnated into some metal foil such as gold, and plated with another metal for complete enclosure. This plating must be very thin to allow passage of the alpha particles.

Beta emitters can be encased in a more substantial material, such as thin metal or plastic foil. Beta particles are more penetrating than alpha, and should be utilised only in an area inaccessible to personnel for a distance of several feet from the source, or where shielding material is placed between the source and the operator.

Gamma emitters present a serious shielding problem. It is probable that only large gamma sources will find eventual application because of the relatively low ionisation per unit volume. With such large sources, personnel would have to be kept hundreds of yards from the eliminator, or several feet of concrete would be required for shielding. Gamma sources could be totally enclosed in rugged containers, thereby eliminating the problem of dispersal.

(*Concluded on page* 17)

The Technology of Automatic Welding in the Soviet Union

RECENT ADVANCES

By J. MANNIN.

This contribution is the second part of a review of new achievements in the technology of automatic arc welding under flux, reported in Russian sources. The period under review covers the four years following the consolidation of the basic techniques in about 1948. *The first part of this contribution to the author's series of articles on Russian Mechanical Technology introduced the need for development in this field and classified the various items of actual progress made. Some of these were discussed in detail, namely, improvements in steel specifications and the introduction of the* semi-automatic *equipment known as the "hose apparatus." This month, the author continues his detailed discussion of other significant advances.*

Another method of semi-automatic welding by a submerged arc under flux has been devised and tested by one of the manufacturing organisations, and experiments have encouraged further development. A manually propelled welding head has a mechanism for an adjustable, but constant, rate of feed of an electrode wire unwound from the reel carried with the head. A flux container is also attached. The head is guided by the seam and supported on a roller, and only the rate of advance along the joint is determined by the operator's skill. This head weighs only 7 lb and can be used for welding speeds of 15 to 80 metres per hour. At a mean rate of advance of 40 m/hr, the productivity of the device is about 7 times that of manual welding. The diameter of electrode wire usable in the miniature head is between 3 and 5 mm.

The next most important development of welding equipment, namely, the automatic welding by a three-phase arc under flux has been described in some detail in "The Engineers' Digest," Feb. 51, pp. 56-57. A more recent development has been embodied in equipment produced by the Central Research Institute for Transport Machinery and issued under the designation "TGZ 3-phase Welding Head," several variants of which exist.

The chief advantages of the three-phase arc are well known. Briefly, these are:—load balancing of a three-phase supply; increased stability of a three-phase arc which permits a reduction of open-circuit voltage of the welding transformer and, therefore, an increase in the power factor of the installation; a better fusion factor particularly as regards the fusion of electrode metal. It has been found that in three-phase arc welding the amounts of parent metal and electrode metal are nearly equal, and owing to the simultaneous feeding into the welding bath of two or three electrode wires, the number of welding passes in the butt joints between very thick plates can be reduced.

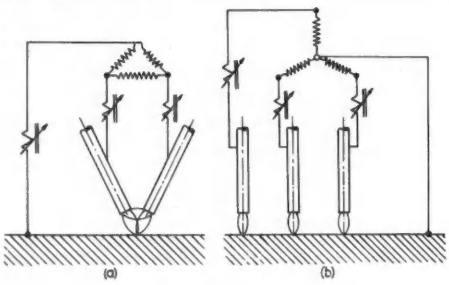

Fig. 4

The three-phase head has been designed to permit a number of variants in the electrical scheme shown in Figs. 4 and 5. At the same time, the great sensitivity of the process to the relative positions of the electrode ends and the joint edges made it necessary to pay special attention to an automatic guiding device which has been designed on the principle of an electric tracing attachment operating as a follow-up mechanism.

The tracing roller follows the clearance between the edges of the welded components. When the displacement of the tracing roller from its horizontal and vertical position exceeds certain set values, micro-switches are actuated to operate an electric drive, which, in turn, causes the welding head to follow the joint line.

It will be recalled that the overall increase in productivity of the three-phase arc compared with the single-phase arc under the same conditions is between 2·1 and 2·7 times.

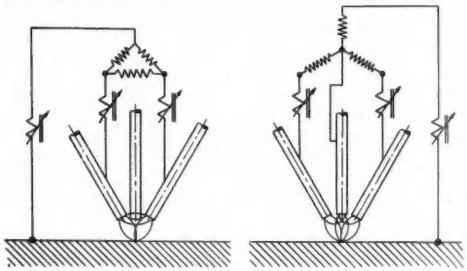

Fig. 5

The twin-arc process is based on the properties of the welding arc with an electrode inclined backwards in relation to the direction of advance. The vertical electrode does not allow welding speeds in excess of 60 m/hr in the welding of steel sheets of 6 to 12 mm thickness. The inclined electrode permits almost twice the speed, but there is some sacrifice of the depth of the seam. Welding with two arcs combines high speed with full depth. The seams obtained with a vertical electrode, an inclined electrode and two electrodes are shown in Fig. 6. The twin-arc process with separately fed electrodes relies on the use of normal sources of power and normal welding heads capable of feeding electrode wire up to 6 mm in diameter. Standard types of fused flux can be used.

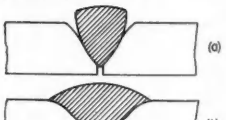

Fig. 6

In twin-arc high-speed welding, the functions of fusing the parent metal and of ensuring the normal formation of the welding seam are divided between the two arcs. The result of this division of functions is that in the welding of a joint of 9 mm thickness at 75 m/hr, the current in each arc need not exceed 900 A. To achieve the same result with a single inclined electrode, a current of 2,500 A would be necessary and an electrode wire of 10 mm diameter would be required. It was

found from experience and confirmed by X-ray investigation that the distance between the two arcs should be about 45 mm. With this distance, both arcs form a single bath of molten metal. As indicated in Fig. 6, the depth of fusion actually exceeds that of each arc individually and so does the width. The stability of the arcs is increased by their interaction, and it is not necessary to increase the open-circuit voltage of the welding transformer beyond 80 volts.

It can be guessed from Fig. 6 that the percentage of parent metal in the seam obtained by the twin-arc process is rather large. A further refinement of the twin-arc process is therefore achieved if this percentage is reduced by adding metal from a filler wire. In welding mild steel of 9 mm thickness with a speed of 120 m/hr, parent metal makes up 80 per cent of the seam. Filler wire can reduce this percentage to 65 per cent. Moreover, the introduction of filler wire into the twin-arc zone is much easier than the introduction of filler wire into a submerged single arc. In this case, which has already been investigated in 1943 and found unsuitable for practical use, an extremely accurate control of the feed of filler wire is necessary. This precision control is quite unnecessary in the twin-arc process. Another advantage resulting from the use of a filler wire is that the heat which is used to melt it would otherwise be expended on melting an excessive quantity of flux. The addition of the filler wire reduces the consumption of flux from 1,000 gr/m to 650 gr/m, i.e., from three times to twice the flux consumption for a single-arc process.

Looking again at Fig. 6 it will be seen that the form factor of the twin-arc seam is more favourable, and this is especially important in fillet joints.

It has been observed that the relation which exists between the length of the molten pool and the power of the arc is maintained in the twin-arc process. With a combined power of 150 kW, a length of pool of 400 mm can be reached. This length has an effect on the formation of crystals which appear in the finished seam. The large volume of the pool is responsible for the very pronounced effect of the inclination of the joint to the horizontal. Less than 1 degree can change the percentage of parent metal in the seam by about 20 per cent.

Experimental installations for the performance of the twin-arc process were built and tested by the Ukrainian Institute for Electric Welding. Suspended automatic heads and automatically propelled units were tried with success.

The die forming of automatic welding seams was developed in order to achieve the automatic welding of vertical, inclined, and overhead seams. A water-cooled copper die is moved along the line of the joint in the upward direction tightly pressed to the component. The welding head advances along the seam together with the die and feeds electrode wire into the welding zone which is situated in the upper part of the die. The welding head has a hopper attached to it for pouring granulated flux into the zone of the welding arc. In order to ensure a uniform process, a constant level of the welding pool in relation to the die must be secured. At small component thicknesses and with accurate preparation of the joint edges, self-adjustment of the level can be relied upon. With thick-gauge components and uneven edges, automatic level control is necessary.

The crystallisation process, which takes place under more closely uniform conditions of directionally pronounced cooling, gives rise to needle-shaped crystals normal to the surface of the seam. This renders improved mechanical qualities which are entirely due to die forming, since they were achieved on both vertical and horizontal seams.

Improvement of joint quality, and reliability, extension of automatic welding to materials other than low carbon steels, joints of very large and very small thicknesses, and the evolution of new fluxes, are all associated with the metallurgy and chemistry of the metal and flux system. Advances in these directions depend on new knowledge gained regarding the metallurgical phenomena in the welding process. This knowledge is complex because of the many constituents and factors involved. Many investigations into these problems were made, often of a fragmentary nature, or yielding conflicting results. The somewhat confusing situation was recognised three years ago, and one of the tasks of welding science formulated by a conference on automatic welding was the "generalisation and coordination" of the many disjointed items of information on the interaction between flux and metal. Some light on this situation was shed more recently by an authority who questions the fundamental suitability of fused fluxes.

It is known that fluxes from which the chemical constitution of the seam material cannot be enriched are not suitable in automatic welding in association with low carbon electrode wire, even for joints of low carbon steel. However, the alloying properties of fused fluxes are rather limited. These fluxes are usually silicate systems which can take into solution oxides and certain salts of metals, but not pure metals. The most widely used fused fluxes perform the function of a moderate enrichment of the metal with silicon and manganese owing to the reduction process of SiO_2 and MnO which takes place. The satisfactory welding of low carbon steel with the ordinary low carbon electrode wire is only possible with fused fluxes containing more than 30 per cent of MnO, but even then only if the quality of the parent metal is high.

It was soon discovered that even small departures from optimum conditions, such as the presence of rust or scale, an increased content of carbon, sulphur or phosphorus, not fully killed steel, unfavourable joint shape and other conditions, could result in faults such as the formation of cracks in the hot state (hot cracks), porosity, or inadmissible reduction in the physical qualities of the seam (cold brittleness). The more difficult demands set by high carbon and alloy steels could be expected to meet with the greatest obstacles before welding techniques suitable for workshop use could be developed.

It was natural to consider several avenues likely to surmount the difficulties introduced by the extreme sensitivity of the process. In America, the composition of electrode wire was the first and most successful line of attack. Russian technicians have rejected this approach except in special cases, on the grounds that the problem of supply of a large variety of electrode wire specifications and the administrative problem of stocking and selection by the user, were demands which should be avoided. This rather extremist exclusion of a method of improvement which, in view of the wide employment of automatic welding in the Soviet Union, must be most fruitful and effective, is not easy to understand. One is almost tempted to think that the desire not to follow in the footsteps of American techniques has been stronger than technical sense.

The other approach, which is effective mainly in ensuring consistently good qualities of joints, was the carrying out of painstaking research into the effects of the minutest variations in the various constituents of the welding process, followed by a refinement of requirements and a tightening of specifications. This method was pursued by Soviet welding technicians with considerable industry, skill and success. Naturally, the practical application of the results of this pursuit involved industrial decisions on some scale. In the foregoing we have seen some evidence on the conflict of opinion with regard to the manufacture of special steel specifications. Another practical result was a considerable tightening of the process control in the manufacture of flux.

For ordinary low carbon steels, considerable trouble

has been experienced with various impurities, mainly phosphorus, sulphur, hydrogen and nitrogen. Phosphorus is an inevitable companion in high manganese flux. On the other hand, high manganese content (not below 38 per cent MnO) is essential to counteract the tendency of sulphur to cause hot cracks. Very fine limits have to be observed, but to some extent the impurities in each part of the parent metal, electrode wire, and flux system can be interchanged with those in another part. Thus, recommendations are given which state that a certain fraction of phosphorus in the flux can be tolerated above standard, provided parent metal is a certain fraction below standard. On the whole, for reliable welded structures, only first quality electrode wire with especially low S and P content and equally closely controlled limits in the parent metal and the flux are essential. The phosphorus trouble does not seem to have been fully solved, however, and a previously undiscovered direct transfer of phosphorus concentrations in the flux has been revealed, resulting in a new demand on the exclusion of such concentrations attainable by close control of temperature in the flux fusion process.

The main reason for seam porosity has been found to be the solution of hydrogen in the metal closely followed by the absorption of nitrogen. The best antidote is the fluorine salt constituent in the better-quality fluxes which is also beneficial in reducing the sensitivity to rusty edges and the tendency for the formation of oxides which can appear as inclusions in the seam. Fluorine salts are greatly disliked by welders on account of the formation, particularly with silicon, of unpleasant and highly toxic gas. Some investigators have tried to eliminate fluorine altogether, but the prevailing school of thought is that its presence is indispensable and that its ill effects must be neutralised.

Another method of overcoming the metallurgical difficulties already mentioned is the partial removal of the difficulties by exclusion, as far as possible, of the parent metal from the seam by introducing the largest possible percentage of electrode wire material. We have seen that this is successful in many cases, though, in fact, from the design point of view this method is the joining of high carbon steel, or in some cases, low-quality steel, by means of what could be described as high-purity low carbon welding seams.

In many cases it has been found possible to ensure the soundness of welded joints by empirical variations of flux composition, percentage of electrode material in the seam and control of the welding process. The basic sensitivity mentioned above is reflected in the elaborate instructions needed. Each type of welding operation requires its own extensive set of process control rules. The underlying empirical conceptions on the part played by various constituents of flux are not very reliable, sometimes even conflicting, and it is difficult to perceive a clear pattern. There is little doubt, however, that even without theoretical conceptions of general validity, repeatable and consistent results have been obtained, provided departures from the original conditions underlying the investigation were avoided. Most spectacular are the achievements in high-quality welding of thick-walled boiler drums (3 to 4 in.) of both low carbon and molybdenum steels.

The resistance to the use of special electrode wire had to be given up in the automatic welding of austenitic, including stainless, steels. It is known that these steels require, after fusion, an enrichment with an oxidising alloying element; among such elements, titanium and columbium have been found suitable. This is needed to prevent the inter-crystalline corrosion which otherwise causes an erratic instantaneous destruction of joints. Automatic welding of these steels has been successfully performed with basic medium manganese fluxes, but the introduction of titanium oxide into the flux has proved useless, since no absorption of titanium in the flux takes place in the welding process. Electrode wire with high titanium and columbium content was thought necessary. Soviet welding technicians are now engaged in a search to achieve satisfactory joints without columbium which has been declared a "deficit material." Some success has been reported.

Lastly, another avenue, regarded by its originator as highly promising to overcome the precariousness of the chemical compositions of the various components in automatic welding, is the replacement of fused flux by specially designed unfused fluxes. This fundamental idea has undergone some changes in the course of the last few years and has still no wide application in industry. Primarily, an unfused flux which is a mechanical mixture of various powders can have any desired composition. This quality of powdered materials has been an attraction in many branches of applied science, but is not without its difficulties. The constituent parts have a tendency to separate by density and particle size, and their pouring qualities may be inadequate; applied as a flux, such mixtures have an excessive porosity for gases and the finest powders are blown away by the gases produced by the arc. Various ideas were tried to overcome these disadvantages, including the double flux method, but in its latest form this development is designated by the term "ceramic flux." In all cases the powdered flux material, mixed with waterglass, is dried and granulated. In this form it is plain that fluxes with almost any degree of alloying properties can be produced to fulfil the most diverse demands made by the material of the welded components. This development is in its infancy but promises to solve many problems of the welding of rusty and low-quality steels as well as that of alloy steels.

Several types of welding operations on non-ferrous metals have been performed under flux with non-fusing electrodes. A carbon electrode has been used successfully on an industrial scale in the welding of copper. The welding of joints between steel and brass has also been successfully performed with a carbon electrode under a high manganese flux. An advantage of this process is the absence of toxic zinc vapours, which are so troublesome in the open welding of brass components. The welding of aluminium alloys with a tungsten electrode under special fluxes developed for this purpose has been successfully performed. The fluxes contain ordinary salts employed in the metallurgy of aluminium alloys fused at a temperature of 800° C and granulated. The consumption of the tungsten electrode was found to be between 0·015 and 0·06 grams per running metre of seam.

Automatic welding in the Russian winter has been the subject of continuous research, but the views held have undergone a change during recent years. Prior to 1947, some misgivings existed about automatic welding at really low temperatures down to —40° C. It was thought that porosity and the formation of cracks in the welded seam were more likely when the welding operation was performed in the cold. Such welding operations were therefore discouraged and, the recommendations conclude, "it is advisable to consider the question of heating the welding shops of structural engineering works." (!) These recommendations were severely criticised because they set a limit to the progress of vital construction work during the winter months and interfered with plans judged to be of the greatest economic importance.

Subsequent investigations revealed that some of the earlier conclusions were caused by the general extreme sensitivity of automatic welding to a variety of metallurgical and chemical factors, a sensitivity which we have mentioned before. The introduction of the improved high manganese flux AH-348 and of high-purity electrode wire removed many of the accidental causes of welding faults, and isolated the influence of ambient temperature. This separation of causes showed that the effect of severe frost was confined to the cooling rate after the welding cycle. A critical rate of cooling can

be defined as that below which no difference is observed. Cooling at a supercritical rate causes crack formation during the cooling period. The rate of cooling is determined not only by the ambient temperature but also by the cross-section of the seam and by the gauge of the components joined. At an ambient temperature of —40° C, but under otherwise normal conditions, steel plate thicknesses up to 25 mm can be joined in any desired way without exceeding the critical rate of cooling. Small-section fillet joints between steel thicknesses of 40 mm give rise to rates of cooling above the critical and should be avoided in welding under severe frost conditions. These conclusions apply to low carbon steel, and the numerical values must be amended for higher carbon steels.

Welding under flux is particularly adaptable for performing plug welding operations.

(1) The arc can be struck at currents above 400 A, following a light contact between the electrode and the component without the need for subsequent separation of the electrode.
(2) Owing to the high stability of the arc under a suitable flux, a stationary electrode will melt to a distance of up to 35 mm.
(3) At currents above 1,000 A the arc is hardly influenced by the diameter of the electrode.
(4) At very high currents (above 4,000 A), the penetration of fusion reaches 20 mm.

Automatic plug welding is based on these properties. The electrode clamped in the electrode holder is lightly pressed against the component. The electrode is then surrounded with a heap of flux to a height depending on the welding process and the thickness of the component. When the welding transformer is switched in by means of a contractor under push-button control, the arc is struck immediately and the component is fused to a depth depending mainly on the current and the electrode diameter. The electrode melts over a length depending on the properties of the flux and the voltage of the arc. The arc breaks automatically and the welding process is stopped.

Special " pistols " exist for carrying out this process. The time per plug can be reduced to 7 secs, and under favourable circumstances welders have attained 600 plugs per hour. It has been claimed that automatic plug welding causes considerably less distortion of sheet components than manual plug welding. The same equipment can be used for the welding of blind plugs, performed without prior drilling of the upper component, as well as that of open plugs, wherein the hole in the upper component has a diameter leaving a clearance of between 2 and 6 mm with the electrode. The high productivity and reliability of the plug welding process under flux have led to the belief that plug welding (or electric rivetting, to use a literal translation), is regarded by Soviet welders as a method of joining with a considerable future.

Another specialised automatic welding " pistol " is used for the welding-on of studs by an arc under flux. In this process the stud itself is the electrode. It is held in the pistol by the plunger of a solenoid, the winding of which is in series with the welding arc circuit. The pistol on its tripod is placed upon the component, and the plunger, with previously inserted stud, is pressed down by a spring until the bottom of the stud reaches the surface of the component. The base of the stud is then surrounded with a heap of flux. A starter button causes a contactor to switch in the welding transformer, and start the welding current, which, at the first instant, is the short-circuit current. This current actuates the solenoid, which raises the plunger against the spring and creates an arc, between stud and component, which melts the end of the stud and a region of the component underneath it. A time relay switches off the welding current, whereupon the plunger is released and the spring is free to press the stud against the surface of the component. This is the actual welding operation. It is claimed that the strength of the joint by which the stud is attached to the component exceeds the strength of the stud. Attachments for containing the flux in the welding of studs to inclined, vertical and overhead surfaces have proved successful. Removable dished washers have been used on some scale. Another method has been tried experimentally with considerable success. In place of granulated flux, protective cylindrical covers of ceramic material can be used to isolate the arc.

Most of the innovations discussed here were developed in answer to an immediate practical demand, and it is rare to find that the report of a new process or principle is not followed within a year by the description of a practical installation employed in the manufacture of a specific article. The details embodied in such installations are usually competent and often stimulating to the practical engineer, but do not possess enough fundamental novelty to merit inclusion in this survey.

Here we conclude our review of Automatic Welding in the Soviet Union. This field of technology was selected for more detailed attention because it is one of those where the engineer is interested just as much in learning about Soviet engineering as in learning from it, wherever it has made original advances of great practical importance.

The following articles in this series will deal with casting and forging technology. It will be seen that foundry work is fairly advanced in the U.S.S.R., but the press working of metals is officially recognised as one of the weak spots in the Russian manufacturing industry.

RADIOACTIVE STATIC ELECTRICITY ELIMINATORS

(*Concluded from page* 13)

Commercial alpha-particle eliminators have been used most extensively in paper, printing, textile and packaging processes. Dusting phonograph records, processing motion-picture film to prevent the adherence of dust, photographic enlarging and colour film processing are other industrial applications. Alpha emitters have been installed to take the charge from the laminated glass of aeroplane windshields that may shatter under lightning-like discharges. Beta-ray eliminators utilising strontium^{90} (one of the products of nuclear fission) and gamma-emitting cobalt^{60} (artificially produced radioisotope) have been developed and operated.

The increasing availability of large amounts of inexpensive beta and gamma-emitting materials suggests two applications of importance to the metal-processing industries. These are speculative in nature and have not yet been commercially exploited.

First is in industrial grinding operations where a very small particle size is desired. Additives or other grinding aids are commonly used for this purpose. An important function of these additives is to eliminate the static charge that builds up and prevents further grinding to finer size. The use of radioactive static eliminators to ionise the ambient air might obviate the need for additives in fine grinding.

The processing of magnesium, aluminium, and zinc metal powders presents an explosion hazard. Except when highly compressed, metallic powders are generally insulators ; consequently, during normal handling in such processes as sieving, passage down a chute, or pneumatic carriage through ducts, a considerable electric charge can accumulate. The discharge of this static, either through a spark or leakage through a high resistance, may ignite the metal powder when it is in a dust cloud or in a loose heap. Ionisation of the air at the sieve, along the chute, or along the free fall of the metal powder would eliminate the danger of ignition from this source.

GERMANY

Test Procedures and Methods for Eliminating the Measuring Errors of Thermometers

By F. LIENEWEG. (From *Feinwerktechnik*, Vol. 56, No. 11, November, 1952, pp. 325-332, 14 illustrations.)

(*Concluded from December issue*)

THERMOMETER TESTS UNDER OPERATING CONDITIONS AND ELIMINATION OF ERRORS

Under operating conditions, measurement errors can be caused by (a) erroneous indications of the measuring instruments and the thermometers themselves, and (b) incorrect installation of equipment. It is, therefore, essential to verify first that the thermometers are correctly installed and that the right temperatures are being measured, and to examine periodically the measuring arrangement.

ERRORS IN MEASURING ARRANGEMENTS

Temperature errors: Every indicating instrument has a temperature error, that is, its indication is varied by temperature. The indicating units should, therefore, be set up at positions where there is a uniform temperature level of about 20° C. The magnitude of the temperature effect varies considerably according to the range of temperatures which is to be measured. In multi-range instruments for resistance thermometers, the temperature error is usually related to the scale length, whereas in moving-coil instruments it is given relatively to the deflection value. The temperature error should be indicated as a percentage for a 10° C temperature variation on each instrument, so that the magnitude of the error will be clearly apparent to all users.

A further temperature error occurs if the copper leads as well as the thermocouple and its compensating leads alter their resistance values, owing to changes in temperature relative to the temperature at which they were calibrated. Subsequent adjustments are therefore required for the leads if their temperatures are varied. Such checks should be made periodically, in order to ensure that the installation always remains in good condition.

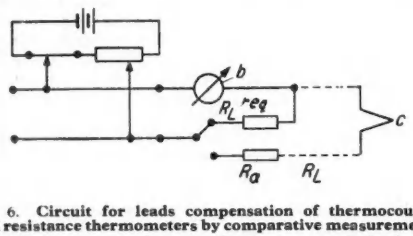

Fig. 6. **Circuit for leads compensation of thermocouples and resistance thermometers by comparative measurements.** b = galvanometer, c = thermocouple, $R_{L\,req}$ = required value for leads resistance, R_L = leads resistance, R_a = compensating resistance.

Leads compensation: The testing and checking of compensating arrangements for resistance thermometers is carried out for a two-wire circuit with the aid of a set of standard resistances which are substituted in the circuit. For three-wire systems, it is generally necessary to check the leads with a measuring bridge. The leads compensation for resistance thermometers and particularly for thermocouples can be carried out simply and rapidly with the aid of the potentiometer arrangement shown in Fig. 6. Short-circuiting the resistance thermometer, or removing the thermocouple (or using a cold thermocouple), the required resistance value R_L for the leads is switched into the circuit, the indicating device is set to any arbitrary deflection, and then after switching back again to the original circuit including the lead resistance R_a, compensation is carried out until the same deflection is obtained in both cases.

Another method for thermocouple compensation, which is applicable when thermocouples are already fitted in position, is obtained with the circuit arrangement of Fig. 7a. The thermocouple, together with its compensating lead c, its connections R_L and balancing resistance R_a, is connected to a potentiometer. In addition, the indicating or recording unit d is also connected, as well as a standard resistor with the required value for the leads resistance, such as, for instance, 20,000 ohms. After adjusting the null-galvanometer to zero, the indicated temperature is read and the original connections are restored for normal operation. The compensating resistance R_a is then adjusted until the same indication is obtained as in the test circuit. This method also takes correctly into account the thermocouple resistance, which exists under operating conditions.

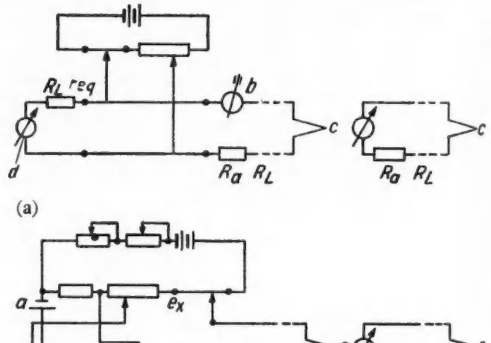

Fig. 7. **Circuits for testing of moving coil instruments used for leads compensation of thermocouples under working conditions.**

(a) Potentiometer system: b = null galvanometer, c = thermocouple, d = indicating instrument, $R_{L\,req}$, R_L and R_a as in Fig. 6.
(b) Compensator system: a = normal element, b = null galvanometer, c = thermocouple, e_x = compensating voltage, $R_{L\,req}$, R_L and R_a as in Fig. 6.

Check tests of indicating instruments and thermocouple voltages: The indication of measuring instruments used with resistance thermometers can be rechecked under operating conditions with the aid of standard resistances, after switching out the thermometer and its connections. The adjusted value for the leads resistance should also be included in the check test.

For the checking of thermocouple measuring arrangements, the potentiometer method or the compensator method of Fig. 5 (see December issue, p. 414) can be employed. The circuits of Fig. 4 may also be used to compare the voltage of the built-in thermocouple with that of a standard thermocouple subjected to the same temperature.

If it is required to make a rapid check of a measuring instrument (such as a temperature regulator, etc.) without removing it from its working position, this can be achieved by means of the measuring arrangement of Fig. 8. As in previous cases, the temperature or voltage is first measured in a potentiometer or a compensator

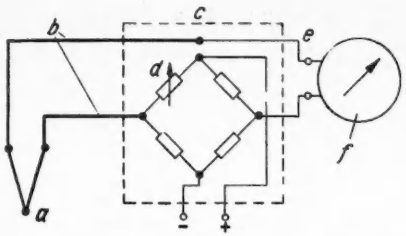

Fig. 8. **Compensating circuit for automatic elimination of influence of variable reference temperatures for thermocouples.**

a = thermocouple, *b* = compensating lead, *c* = compensator unit, *d* = temperature-sensitive resistance, *e* = copper lead, *f* = indicating instrument.

circuit, and then compared with the instrument indication in its normal working circuit. The difference in readings serves to determine the measuring error of the instrument.

It is evident that both the potentiometer system and the compensator system can be developed in such a way as to enable all the tests previously described to be carried out with a single portable-type instrument.

Check of reference temperature and compensating arrangements: Thermocouple measuring arrangements without thermostats or without automatic compensating systems require frequent checking and readjustment of the indicating device to the temperature of the reference point of the thermocouple. When several thermocouples are connected to multiple-switch type indicators or recorders, an adjustment is not possible if the compensating leads are not directly connected to the indicator elements, because the various reference points may be at different temperatures. In such a case it is necessary to take account of the influence of different temperatures by calculations. However, it is not justifiable to use the full value of the difference Δt relative to the reference temperature to which the instrument is adjusted, but one should rather use a somewhat lower value, which is derived from the curvature of the calibration curve for the type of thermocouple considered. The factor by which the temperature difference Δt should be multiplied is, for instance, about 0·90 for iron-constantan elements at 600° C, approximately 0·55 for PtRh-Pt elements from 800 to 1600° C, and for nickel-chromium/nickel elements it is approximately equal to unity over the entire measuring range.

Where thermostatic control is used to maintain a constant temperature at a reference position, this temperature should be checked periodically. If compensating units such as those denoted by *c* in Fig. 8 are used for automatic compensation of variable reference temperatures, it is also necessary to check at intervals the value of the auxiliary voltage source. In a more accurate test, the counter-e.m.f. should also be checked under operating conditions. This is easily performed by short-circuiting the connections of the thermocouple *a* at the compensating unit and measuring the temperature of the latter with a mercury thermometer. After this, an auxiliary voltage is switched in, and the temperature measured with the mercury thermometer must be obtained with an indicating instrument *f* with an error not greater than +2° C. The ends of the thermocouple wires and compensating wires should be at the same temperature as the compensating unit or thermostat in such tests. If the latter units are enclosed in a large housing, this should therefore not include any copper wires but only compensated leads.

The compensating leads from the thermocouple element to the reference point should be at a temperature not exceeding 200° C at the connecting points. At higher temperatures, the thermoelectric voltages of the compensating leads are considerably different from those of the thermocouples. If necessary, the connecting points should be protected by asbestos shields or other suitable arrangements. The correct poles must be connected together, since any poling error may increase the indicating errors when there are variations in the reference temperature.

For very accurate temperature measurements, involving possibly the use of precalibrated thermocouples, it is advisable to consider also the variations in the thermoelectric voltages of the compensating leads from their required value. The temperature tolerances for these leads are the same as for thermocouples. In some cases, if the tolerances are in opposite directions, the permissible limits of error may be exceeded.

In systems with change-over switches, these switches should be checked periodically to avoid measuring errors due to gradually increasing transition resistances. Moreover, checks should be made of the voltages from the current sources and of the insulation condition of the leads.

Checking of radiation pyrometers: When radiation pyrometers are used, they should be carefully checked during operation by means of the tests previously described. The indicating devices are tested in the same way as the moving-coil instruments for thermoelements.

CHECKING OF ERRORS DUE TO THE INSTALMENT OF INSTRUMENTS

Radiation pyrometers: In radiation pyrometer installations, the lenses should be cleaned, whenever necessary, as well as the filters which are provided in ventilated housings for the removal of oil and water vapour from the compressed air. The protective devices must always be in good working order and the compressed-air supply must always be in operation. Special fans can be used for ventilation. The condition of the incandescent lamp should be carefully inspected. If it is not absolutely air-tight, measuring errors may occur owing to cooling arrangements in furnaces operating at pressures below atmospheric pressure. The radiation pyrometers must be set up so that they shall not be disturbed by fumes or flames during operation.

In the supervision of hardening baths the salt vapours can be removed, for instance, by means of an air stream from a blower acting on the bath surface or by introducing a ventilating tube at the bath surface. Measurements in hardening baths can be conveniently made with the aid of steel-type incandescent lamps enclosed at the bottom, or air-cooled lamp units which are immersed in the melt.

In the case of total radiation pyrometers with thermocouples, measurement errors may also arise owing to water vapour or carbon dioxide gases in the furnace atmosphere. Such errors do not affect barrier-layer type cells, as long as the vapours do not condense. Errors of this kind should be borne in mind during inspections of the apparatus.

Resistance thermometers and thermocouples: As the protecting tube of thermometers is exposed to particularly strong corrosive influences in hardening processes, its condition should be examined and the tube should be replaced whenever necessary. Errors in the installation can best be determined by comparative measurements with other thermometers. If it is suspected that the thermocouple or the measuring resistance of the resistance thermometer has altered during operation, a check should be made, using for thermocouples the potentiometer or compensator method. It is frequently simpler to make an independent measurement with a calibrated standard thermometer, which is either inserted in the protecting casing of the thermometer under investigation, or placed in its immediate vicinity.

Measurement errors due to the installation may also occur owing to heat dissipation and radiation. At low

temperatures, the heat-dissipation error predominates, whereas radiation from the walls on to the thermometer cylinder is the main disturbance at high temperatures. In order to determine whether such errors are present, it is convenient to use a special thermometer with a low radiation error and, if possible, without a protecting cylinder, which is placed close to the thermometer to be tested. A mercury thermometer or a thermocouple can be used for this purpose. In comparative measurements of this kind, it is necessary, however, to take account of the different thermal inertias of the thermometers and to wait until stationary conditions are established.

To reduce radiation errors to a minimum in such comparative measurements, the thermometers may be covered with one or several protective cylinders. This, however, increases the time-lag for a correct indication. For rapid tests it is convenient, therefore, to use a bare thermocouple which is surrounded by a thin shield of bright silver. Silver has a low emission coefficient of only 3-5 per cent as compared with 70-90 per cent for most other metals. As a consequence, the transmission of heat through radiation is reduced to about one-fifteenth and the temperature indication is practically free from error.

If it is not possible to carry out measurements of this kind, in measurements of high gas temperatures the temperature must be determined with ejection or suction type thermometers, the gases being aspirated through a tube introduced in the furnace and the temperature is determined by means of a built-in thermocouple. For protection against radiation errors, the unit is made in the form of two concentric tubes with the thermocouple wires situated between the two cylinder walls. Owing to the good thermal conductivity of this arrangement, the gas temperature can be determined very accurately and the measuring error of the thermometer being investigated can thus be obtained.

For measurements in the lower range of temperatures, i.e., up to about 500° C, it is possible to eliminate the measuring error which is due to heat dissipation from the bottom of the protecting tube to the wall or to the protruding thermometer head by various methods which are given in the following lines :—

(1) A greater portion of the thermometer is inserted in the furnace. This measure is particularly effective when the heat transition is small between the measured medium and the tempering agent (air). With greater heat transfer values, for instance in water or in salt baths, the temperature error is only slightly reduced by increasing the length of the protecting tube and in such cases fairly short tubes are sufficient.

(2) The temperature of the walls must be maintained by adequate insulation, in order that the temperature of the thermometer cylinder shall correspond as closely as possible to that of the medium investigated. This reduces both the heat dissipation and the radiation error.

(3) The wall thickness of the protecting cylinder should have the smallest possible value consistent with strength requirements.

(4) The thermometer should be fitted at a position where the flow is as great as possible.

(5) The temperature-sensitive element should be situated so that its length is in the direction of the gas flow, wherever possible.

The order of magnitude of the temperature error due to heat dissipation can be determined by means of thermometer characteristics, on the basis of calculations and tests made in recent years. After performing initial tests to determine the temperature error in air and water, it is possible to assign characteristic figures to the type of thermometer considered. From these the measuring error can be derived for any other media. By means of these thermometer characteristics it is also possible to determine the temperature error of thermometers under operating conditions, provided that simultaneous measurements are taken of the indicated temperature and the wall temperature at the measuring position, for instance by means of a thermocouple. The experimental curves show that the measuring error can only be reduced to a slight extent in media with good heat transfer values, and that increases in heat transfer coefficients have only a secondary effect (see Fig. 9).

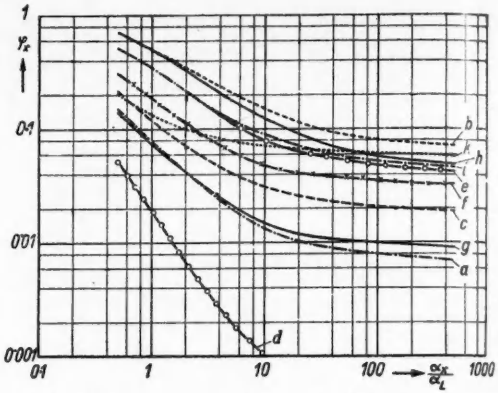

Fig. 9. **Thermometer error due to heat dissipation, plotted as a function of the heat transfer coefficients α_x/α_L.**

φ_x = $(t_m - t_1)/(t_m - t_w)$,
t_m = temperature of the medium x,
t_1 = measured temperature,
t_w = temperature at the screw-in position of the thermometer,
α_x = heat transfer coefficient of the medium x,
α_L = heat transfer coefficient in air,
a = resistance thermometer insert,
b, c = resistance thermometers in protecting tubes of 170 and 300 mm length,
d = thermocouple insert,
e, f = thermocouple in protecting tubes of 160 and 250 mm length,
g = liquid thermometer insert,
h, i, k = liquid thermometer in protecting tubes of aluminium, aluminium with fins, and steel, all of 120 mm length.

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Multi-Purpose Liquid Plastic

The Lockheed Aircraft Corporation has developed a multi-purpose liquid plastic for soundproofing and insulating. The material is valuable in aircraft construction as a structural stiffener that can be poured into cavities of complex parts.

In its liquid state, the material can be poured in place, sucked into cavities through holes too small for pouring, or flowed into casting blocks for carving to size. From a liquid it expands to fill the structural cavity into which it is poured. Other applications include filler for aircraft ailerons, rudders, elevators and wing trim tabs ; additional strengthening of shock absorbing wing structures ; antenna housings ; insulation in cabin ventilating systems.

The plastic provides good insulation against shock, sound, heat, cold, vibration and electricity. It can be poured and set under ordinary room conditions, without heat or special equipment. During foaming it sticks, without glue, to wood, paper, fabrics, metal and fibreglass.

Composite Metals—A New Key to Design Flexibility

By J. OTTMAR. (From *Product Engineering*, November, 1952, pp. 153-157, 4 illustrations.)

The development of new metal bonding techniques has made possible the metallurgical bonding of practically any combination of malleable metals. These composites (clad metals, sandwich metals, or laminated metals) consist of two or more uniform layers of single metals bonded together, usually under heat and pressure. They combine many desirable engineering properties which are not available in the separate metals, such as high strength and low weight, and improved fabricating characteristics, and these are frequently obtained at a lower cost by employing fewer critical alloys.

Bonding and Manufacturing Techniques

There are two bonding methods generally used, viz., the solid-phase method and the liquid or semi-liquid method. In the former, the parent metals are bonded directly by applying pressure at high temperature. In many cases, hot rolling followed by cold rolling is used to obtain improved bonding and reduced thickness.

The liquid or semi-liquid method is frequently used to bond precious metals to base metals. In this method, a thin sheet of high-temperature brazing alloy is placed between the metals to be bonded. After brazing, the ingot is put through a series of cold rolling and annealing operations.

Composite metals required for deep-drawing or other forming operations should have a sufficiently thick cladding layer to prevent excessive stretching and possible fracture of the outer layer. Blanking and forming, spinning, drawing etc. can usually be performed. It is generally advisable to base these operations on the physical properties of the less ductile of the metal layers under consideration.

In welding operations, care should be taken to avoid fusing of the preferred metal surface with the core or backing metal, since this might produce an unsuitable alloy at the surface. For welding on the clad side of a seam, the welding electrode should be richer in the special elements than the cladding layer. The dilution can also be kept to a minimum by depositing a series of small beads in the welding groove.

A wide range of composite metals is now commercially available and will be described in the following lines. In addition, various other composites, such as nickel-clad copper, copper-clad nickel, copper-clad magnesium, calcium-clad nickel and molybdenum-clad cupro-nickel, have been produced for special applications.

Aluminium Base Composites

Copper-clad aluminium is extensively used in electronic applications for chassis, brackets, and component housings. Its light weight makes it particularly suitable for aircraft equipment and the copper surface is ideal for soft-soldering operations. Aluminium with copper clad on one or both sides eliminates galvanic couples and corrosion effects in split-bolt and washer type connectors for aluminium conductors. The aluminium side contacts the aluminium cabling and the copper side contacts the copper switchgear terminal. Single or double clad surfaces provide a base for further finishes or electroplating. Copper-clad aluminium is also used for connector blades, busbars, stamped electronic circuits, emblems, etc. fabricated by coining, as well as for condensers and heat transfer assemblies.

Silver-clad aluminium is employed for high-quality contact components not subjected to flexing, and results in an appreciable saving in both weight and cost. Recently, *tin-clad* and *zinc-clad aluminium* have been produced and provide non-porous surfaces for soft-soldering. *Silver-lined aluminium* tubing is frequently used for rectangular wave-guide tubing. It can be supplied with a thin copper layer on the outer surface for soft-soldering. *Silver-lined brass tubing* is also produced.

Clad Brazing Alloys

Brazing alloys and parent metals are bonded and rolled in the same way as other composite materials. With these, the separate production of small pieces of brazing alloy and their handling during brazing operations is eliminated. The number of surfaces to be cleaned and fluxed is reduced, and uniform wetting of the surfaces to be joined is also ensured. Ductile shim material with silver brazing alloy clad on both sides is widely used for the *sandwich brazing of carbide tips* to cutting tools. Only one piece, instead of three as previously, has to be cut and handled, and an improved bond is obtained. Materials with a thin backing layer of brazing alloy are also used for fabricating button type electrical contacts.

Iron and Steel Base Composites

Owing to its ability to resist corrosion at high temperature, its heat-reflective properties and high mechanical strength, *aluminium-clad steel* is frequently used for

Properties of Various Copper-clad Aluminium Materials.

(S = soft, H = hard (40 per cent reduction), p_y = yield strength (0·2 per cent offset), p_T = tensile strength, e = percentage elongation, $V.H.$ = Vickers hardness (100 gr load, sheet 0·020 in.), E = modulus of elasticity, ρ = density, α = heat conductivity, β = linear expansion coefficient (0–100° C), ρ_{el} = electrical resistivity).

Type Cu	Al	Cu		p_y ×10³ psi	p_T ×10³ psi	e %	$V.H.$ Al	$V.H.$ Cu	E ×10⁶ psi	ρ gr/cm³	α cal/cm sec °C	β ×10⁻⁶	ρ_d ohms mil ft
10	90	..	S	5·7–7·1	12·8–15·6	31–28	33	70	10·4	3·33	0·54	23·3	16·2
			H	18·5–21·4	25·6–28·5	7–5	47	105	—	—	—	—	—
5	90	5 ..	S	5·7–7·1	12·8–15·6	31–28	—	72	10·1	3·33	0·54	23·3	16·1
			H	19·9–22·8	25·6–28·5	7–5	—	107	—	—	—	—	—
20	80	..	S	6·4–7·8	14·2–17·1	33–30	33	70	10·8	4·0	0·58	22·5	15·7
			H	22·8–25·6	27·0–30·0	7–5	46	105	—	—	—	—	—
10	80	10 ..	S	6·4–7·8	14·2–17·1	33–30	—	70	10·25	4·0	0·58	22·5	15·2
			H	22·8–25·6	27·0–30·0	7–5	—	105	—	—	—	—	—
30	70	..	S	7·0–8·05	17·1–19·9	36–34	33	69	11·5	4·5	0·62	21·8	15·1
			H	24·2–27·0	28·5–32·8	8–6	47	104	—	—	—	—	—
15	70	15 ..	S	7·0–8·05	17·1–19·9	36–34	—	70	10·55	4·5	0·62	21·8	14·4
			H	25·6–28·5	28·5–32·8	8–6	—	105	—	—	—	—	—
Al	..	..	S	5·0	13·0	35	27						
			H	21·0	24·0	5	49		9·8	2·71	0·52	23·8	17·6
Cu	..	..	S	11·0	35·0	36	—	52					
			H	46·0	55·0	5	—	105	16·0	8·93	0·92	16·8	10·4

heat exchanger tubes, space heater and water heater components, ranges, aircraft fire walls, toasters, etc. For outdoor fixtures exposed to atmospheric corrosion, it is being considered as a replacement for copper-alloy shrouds on lamp-base sockets. In many electronic valves, aluminium-clad low-carbon steel strips are employed instead of pure nickel, with savings in cost resulting from the greater number of parts produced per pound of material and the omission of carbonising operations. Matte-finished parts are blackened by firing and have a radiation coefficient of about 85 per cent of a black body. Materials with thin nickel layers on both sides or with 10 per cent cladding of aluminium on one side and 10 per cent pure nickel on the other are also employed for electronic valve components.

For small-arms munitions, clad-steel billets of 2000-3000 lb are being produced. Clad-steel bullet jackets have replaced solid gilding metal and solid cupro-nickel jackets. Salvage of steel and copper is possible by separation processes.

Stainless Steel Clad Metals

Stainless-clad aluminium with high thermal and corrosion resistance is being tried out for many applications. *Stainless-clad low-carbon steel* is another low-cost combination. *Aluminium bearing alloys clad to a steel backing metal* have also been produced.

Stainless-clad copper combines the high temperature- and corrosion-resistance of steel with the high thermal conductivity of copper, which eliminates hot spots. Owing to the reduced rate of heat dissipation obtained with stainless cladding, which acts as a partial heat insulator, the apparent lateral conductivity is higher than that of solid copper, using a 25/50/25 thickness ratio of double-clad stainless on copper. Applications include jet engine and gas turbine components, exhaust manifolds, cooking utensils, etc.

Lead Clad Metals

For acid resistance combined with mechanical strength, or high electrical and thermal conductivity, *lead-clad steels* and *lead-clad copper* materials have been developed. The latter provide improved discharge current when used as anodes in place of solid lead anodes. These composite metals can be easily worked and fabricated. Materials with a single or double clad layer of lead-bearing soft solders are also available.

Rare and Precious Metal-clad Materials

High corrosion resistance, high melting point and light weight are obtainable at reduced cost with *zirconium*, *titanium* and *tantalum* bonded to a common base metal, such as steel or nickel. *Silver*, *gold* and *platinum* clad to stronger base metals are finding increased industrial applications for electrical contacts and crucibles. Rare-metal clad button-type contacts with steel or monel backing facilitate projection welding. In many cases, the backing metal provides additional properties, such as elasticity, stiffness, electrical conductivity and magnetism.

Precious metals and other metals can be stripe-positioned at practically any locations, as through-lay, in-lay or edge-lay, at the top of surfaces, on ribs, etc. Electrical contacts are their principal uses.

Special Spring Materials

Composite materials have also been developed for spring components. For springs which are also required to have a high electrical conductivity, a material consisting of phosphor bronze integrally bonded to both sides of a copper core has been produced. The conductivity of phosphor bronze is only 11 per cent of that of copper. Generally, a thickness ratio of 25/50/25 is used, but various ratios are obtainable, depending on whether requirements are primarily for high conductivity or for elastic properties.

Hardenable carbon steel clad with copper on one or both sides is also made for spring applications. Compared with beryllium copper, it has a higher electrical conductivity, a higher stiffness and is less expensive, but its fatigue resistance is somewhat lower. This composite is employed for thin blade or spiral-type springs, fuse and connector clips not subjected to frequent arcing, as well as for pen and pencil clips with an electroplated finish. The copper layer need only be about 5 per cent of the total thickness of the material.

Thermostat Metals

For thermostat elements, one of the oldest composite applications, suitable mating metals with different thermal expansion coefficients are chosen so as to provide a bending action when subjected to a change in temperature. The materials used are nickel and chromium alloy steels, manganese base alloys, and copper alloy metals, in various combinations.

RUSSIA

Elimination of Residual Stresses in Castings by means of Local Induction Heating

By Y. A. Smolyanitzkyi. (From *Vestnik Mashinostroyenya*, No. 10, 1951, pp. 55-58, 4 illustrations.)

The author describes a method of reducing residual stresses in castings. The discussion follows the time history of temperatures and stresses in a typical casting having the shape of a thick rim, joined across one diameter by a single thin spoke. In the heating and cooling process, five periods are distinguished and the result is explained by means of simple but thorough reasoning. Experimental verification of the expected results has been obtained in a test set-up described in the article.

Residual stresses in castings caused by mechanical constraints on shrinkage cause deformations which often appear only after the final machining, accelerate the failure of components, and reduce their service life.

Results of investigations into a new accelerated method for the release of residual stresses in castings are given in the present paper. Local induction heating can be successfully employed in batch or mass production of grey cast iron components as well as for steel castings after normalising. It is mainly suitable for castings in which a heavy frame encloses and constrains a web or tie of small cross-section (flywheels, gear blanks, etc.).

The proposed process is an application of a method of residual stress removal by means of local plastic deformations at temperatures above the threshold of recrystallisation. Therefore, for the local heating of castings, other sources of heat, such as those using

gaseous, liquid or solid fuel, can be used instead of induction heating.

The release of residual stresses is achieved by quick, local induction heating of small regions in the casting until a plastic state, i.e., a temperature of 700-800° C (red heat), is reached. Under the action of locked-up stresses, plastic deformation takes place in the heated region and residual stresses are greatly reduced. On subsequent slow cooling in still air, high locked-up stresses are no longer formed, because of the small amount of heat stored in the casting and the low degree of heating of the casting as a whole. Local heating is applied to regions of small cross-section in order to achieve fast heating by means of inductors of the simplest design.

Theoretical Basis of Method

Let us consider a casting consisting of a thin spoke spanning a thick rim (Fig. 1). Owing to the thermal retardation of shrinkage, the thin spoke will be found, on complete cooling, to be elastically compressed and the rim elastically extended.

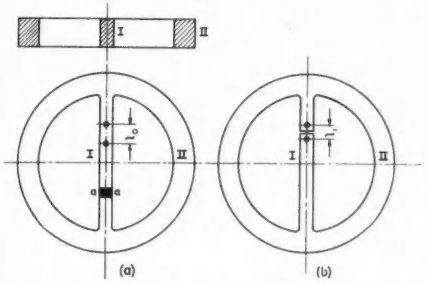


Fig. 1. **Simple casting considered for discussion of theory.**

The magnitude of the stresses in the casting is proportional to the magnitude of the elastic deformations, which can be found from the difference e in the distances between two points before and after cutting the spoke I.

$$e = l_0 - l_1$$

Let the thin spoke I be subjected to quick (induction) heating over the length $a - a$ (Fig. 1a). When the temperature of the heated region exceeds 620° C, the metal enters the plastic state and the locked-up stress causes a plastic compression of the spoke and a steep reduction of the stress follows. The same phenomena take place when the casting is annealed, but the cycle is much longer.

The process of accelerated annealing is represented graphically in Fig. 2, where t_I and t_{II} (Fig. 2a) are the temperature curves during heating and cooling of the thin spoke I and the thick rim II. δ_I and δ_{II} (Fig. 2b, c, d) are the stress curves in spoke I and rim II during the annealing process. The three graphs represent different heating programmes.

The initial state of the casting is given by the points on the ordinate axis (instant τ_i). At this instant, the temperatures of the spoke and the ring are equal to the ambient temperature. The residual stresses corresponding to a compression in the spoke and tension in the ring are shown.

The *first period* is the heating through the temperature range of elastic deformations. This very brief interval lasts during the heating of spoke I over the length $a - a$ from the ambient temperature t_i to the plastic state reached when the temperature has risen to 620° C at the instant τ_1. The spoke temperature within the heated length rises along the curve $t_i - t_{II}$. The temperature of the rim rises simultaneously, but very slowly, along the curve $t_i - t_{III}$. The compressive stress in the spoke increases in accordance with $\delta_{I_i} - \delta_{II}$ and the tension stress in the rim in accordance with $\delta_{II_i} - \delta_{III}$.

The *second period* is that during which heating and cooling in the range of plastic deformations take place. In this equally brief interval (between instants τ_1 and τ_2) the heating of the length $a - a$ to the maximum temperature t_{max} is continued and the subsequent cooling from t_{max} to about 620° C. The length $a - a$ is in a plastic state and a sharp reduction of stress δ_{II} in the rim and of stress δ_I in the spoke takes place.

The duration of the second period $\tau_1 - \tau_2$ has a decisive effect on the magnitude of the residual stresses after annealing and, consequently, on the results of the process. The residual stresses will vanish (Fig. 2b) only after a definite amount of plastic deformation. Below this amount of deformation the final residual stresses will be of the same sign as the initial residual stresses and their magnitude, though reduced, can be appreciable (Fig. 2c). If the second period is too long, the residual stresses will reverse their sign (Fig. 2d).

The *third period* is that of cooling through the region of elastic deformations. The temperature of the spoke is above that of the rim, but the difference is progressively decreasing. In this period $\tau_2 - \tau_3$, the spoke temperature decreases from 620° C to the temperature t_{I3} whilst the rim is heated by conduction

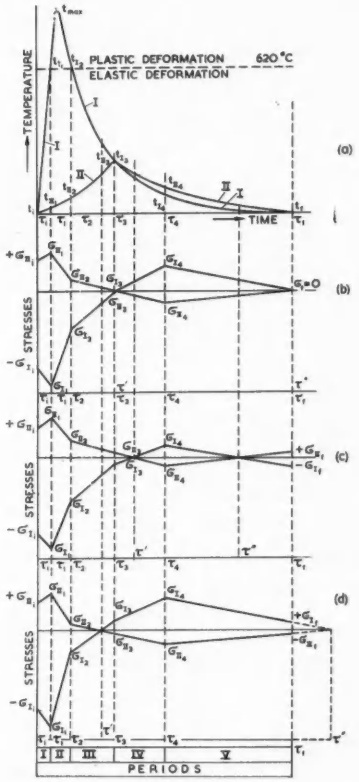


Fig. 2. **Time histories of temperature and stresses illustrating the theoretical discussion.**

(*a*) heating and cooling curves; (*b, c, d*) time histories of stresses resulting from different heating programmes.

Plastic deformations.

from a temperature t_{II2} to a temperature $t_{II3} = t_{I3}$; in other words, until a temperature equilibrium is obtained (instant τ_3). The development of stresses is wholly determined by the thermal compression of the spoke and the thermal expansion of the rim and is shown in Figs. 2b, c, and d. It is seen that the stress is decreased in this period.

Depending on the manner in which heating is carried out, three cases are possible, see Figs. 2b, c, and d. In the first case the stresses at the conclusion of the third period vanish and the instant τ_3 coincides with the instant τ' at which the stresses vanish for the first time. The absolute magnitude of deformations in the third period can be below the absolute magnitude of deformations at the instant τ_2. In this case, when the temperatures are equalised at the instant τ_3, stresses of a sign equal to the initial stresses remain. The stresses do not vanish until an instant τ' which follows instant τ_2 (Fig. 2c). The opposite case is illustrated in Fig. 2d. The instant τ' when the stresses vanish for the first time precedes the instant of temperature equalisation τ_3. In this case, at the point of temperature equalisation, stresses of opposite sign to the initial stresses arise. Since, beyond the instant τ_3 of temperature equalisation, the cooling certainly proceeds in the range of elastic deformation, the final residual stresses of the period are equal in magnitude and sign to those at the instant τ_3.

During the *fourth period*, rim and spoke cool down together. However, after the instant τ_3 until cooling is completed, the temperature of the thick rim exceeds the temperature of the thin spoke, as illustrated by the two curves in Fig. 2a. At first, the difference in temperatures continues increasing and a maximum is reached at an instant τ_4 which is the end of the fourth period. The stresses in the rim and spoke increase progressively and reach a maximum at the instant τ_4 at which the rates of cooling of rim and spoke are equal. The stresses at this point are the highest attained in the region of elastic deformations.

The *fifth period* follows, during which the cooling rate of the rim exceeds that of the spoke. During this period, the stresses in rim and spoke decrease and the instant at which they vanish is denoted by τ''. If this instant coincides with the instant τ_f of complete cooling of the casting, the residual stresses have been eliminated (Fig. 2b). If the instant τ'' precedes the instant τ_f the final residual stresses will be of the same sign as the initial (Fig. 2c) and vice-versa (Fig. 2d), in which case the final residual stresses will have the opposite sign to that of the initial stresses.

These theoretical considerations were verified by tests on a grey iron casting. It was proved that by means of induction heating to a red heat over a length of 10 mm and subsequent cooling in still air, the final residual stresses could be reduced to one fifth and even one tenth of the initial stresses. In conducting the induction heating operation, no instruments were used and the temperature was estimated by the naked eye. Even this rough and ready method gives highly satisfactory results. The duration of the annealing process is reduced from several hours to several seconds.

Accelerated annealing by local induction heating will be found to be especially useful for the reduction of residual stresses in cast frame and grid structures of grey iron and other materials, and also after normalising for certain types of steel castings in batch or mass production.

U. S. A.

Why 12 Volts?

By H. L. HARTZELL. (From *Automotive Industries*, Vol. 107, No. 9, November 1, 1952, pp. 56-58, 96, 98, 103-104, 106, 108, and 112, 7 illustrations.)

HIGHER compression ratios and better breathing have increased the gas pressure around the sparking plug gap in the new standard engine types and correspondingly higher voltages are therefore required for sparking. Other factors influencing the breakdown voltage are the sparking plug position in the combustion chamber, the electrode material, shape, temperature, and length of gap.

Tests on a single-cylinder variable-ratio engine with plug gaps set at a representative value of 0·040 in. showed that there is a 10 per cent increase in breakdown voltage for each full ratio change. Further tests on a 1946 production engine and a 1952 experimental engine, with used plugs which had 16,000 miles of service, showed that the ignition voltage requirements were 16 kV at 10 mph and 8·5 kV at 90 mph for the older model, as compared with 20 kV at 10 mph and 14 kV at 90 mph for the experimental model.

To determine the "available voltage" at various speeds, the input terminals of a cathode-ray oscilloscope were connected to the secondary terminal of the ignition coil. The longest sparking plug lead (which has the highest capacitance and hence the lowest voltage) was then disconnected from its plug and the lowest voltage pulses developed on that lead under various test conditions were observed on the oscilloscope screen.

The "voltage required" values were determined as the highest voltages required for firing of all plugs under various operating conditions (road load, full-throttle and part-throttle acceleration, and surge or whip driving conditions). Surge and part-throttle acceleration requirements were often the highest, with maximum values at the beginning of each acceleration. An engine can be operated with occasional missing and the available voltage may then be lower than the full voltage required; under certain conditions it may be only 60 per cent of the required value.

Fig. 1 shows the curves for "voltage available" and "required voltage" (the latter for both new plugs and used plugs) obtained from tests on the experimental engine. The increased voltage required with used plugs is due to erosion effects, which increase the gap length and alter the centre electrode shape. In view of the changed shape of the centre electrode, a re-gapping of the plugs will not reduce the voltage requirement. The "available voltage" curve was obtained with a six-volt ignition system, tested with full electrical load (lights, heater, and radio) and a high-limit setting at the breaker points. It is evident from the results that with the six-volt system the new engine models will miss prohibitively and require plug replacements much sooner than older models with lower compression ratios.

To see how the necessary higher voltages can be obtained, it is necessary to consider the electrical characteristics of the ignition system. The ignition coil is a type of pulse transformer. When current flows from the battery through the primary winding, the energy is first stored in the magnetic system, and is

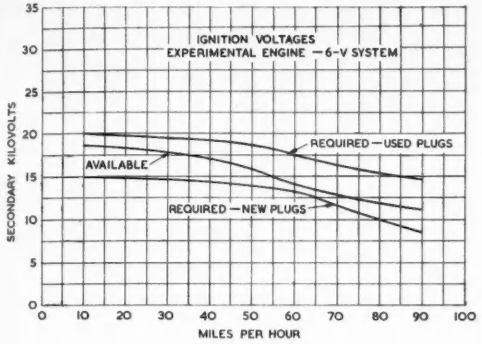


Fig. 1.

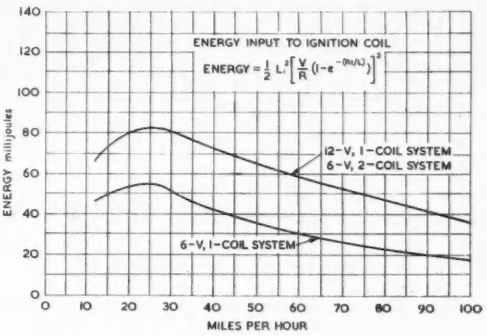


Fig. 2.

equal to $\frac{1}{2} Li^2$ [joules], where L = primary inductance [henries], and i = current through L at the time the breakers open [amps]. When the contacts separate, the energy is transferred to the capacitances in the primary and secondary system. The energy in the secondary is $\frac{1}{2} CV^2$ [joules], where C = capacitance of secondary system [farads] and V = peak voltage [volts]. Although several manufacturers have arranged the secondary leads for minimum capacitance to the ground in order to obtain higher V-values for the same amount of energy available, the increase is not sufficient for the needs of the new engines being developed, so that some method must be used which increases the energy input to the entire system.

The energy input $\frac{1}{2} Li^2$ can be increased by raising the values of L and i. However, the current pulses that can be handled by breaker contacts made of the best material commercially available cannot be further increased without risk of failures in slow-speed driving. Thus, an increase of the primary inductance is the only way to improve low-speed performance.

The value of the current i at the time of contact breaking decreases with increasing engine speed. For any time t [sec] of contact closure, the current can be determined by the relation

$$i = (V/R)\,[1 - e^{-(Rt/L)}] = (V/R)\,G$$

where $e = 2{\cdot}718$, L, V and i being the values for the primary circuit, and R = total resistance [ohms] including the resistances of the primary winding, the leads and harness, ignition switch, distributor leads and contacts, the battery, as well as any other element in series with the coil primary. At low engine speeds, $G \sim 1$ and $i \sim V/R$. At top speeds, however, t is much smaller and $i = 0{\cdot}5\ V/R$. Any increase in L will further decrease the current at higher speeds, and hence the energy input. However, this can be offset by increasing either R or t. The time-factor can be doubled with a two-coil system, which includes a four-lobe cam actuating two separate breakers, each controlling a separate ignition coil. R can be increased provided that V is raised correspondingly, so as to maintain a constant value of V/R. Thus, the same gain in ignition voltage output as with the two-coil system can be obtained by means of a single-coil, single-breaker 12-volt system.

Tests showed that the increased current in the middle and upper speed ranges does not appreciably shorten contact life. The 12-volt coil can be made in the same size package as the present 6-volt coil. With an external resistance made from a wire with a constant-temperature coefficient, in series with the coil primary, the temperature influence will be lessened. The current at break will be lower for the 12-volt coil when cold than for the present 6-volt coil, thus decreasing the tendency of the contacts to oxidise under slow-driving conditions. The considerable increase in energy input obtained with the 12-volt coil throughout the speed range is shown in Fig. 2.

Compared with the two-coil 6-volt system, the single-coil 12-volt ignition system avoids the use of synchronised breakers and gives desirable gains in performance for other components of the electrical system. Its cost is about the same as that of the dual-coil 6-volt system with accessories. The 12-volt system would provide ample reserve in secondary voltage for the new experimental engines with plugs used for 16,000 miles and gaps in the 0·034-0·040 inch range. The plugs could be used for an additional 10,000 miles with gaps increasing up to 0·050 inch before re-gapping. It was found in tests that the 12-volt system can develop sufficient voltage to handle used plugs with 0·040 inch gaps on 12 : 1 compression-ratio engines.

Losses in the ignition system caused by moisture, dirt and leaky cables affect both the 6- and the 12-volt system. They can practically be eliminated by using better cables, good nipples on plugs and coils, and improved distributor caps and rotors for higher voltages. Thus, the 12-volt system will allow continued use of easily-maintained single-breaker ignition equipment for higher-performance engines for many years.

INCREASED GENERATOR OUTPUT

To restore the cranking energy supplied by batteries, the 15 A generators generally used since 1925 have been gradually replaced in many modern cars by 45 A units. The increased output was obtained without increasing the size of the units, by using higher drive ratios, higher speeds and forced ventilation. However, it appears that just about the maximum is being obtained from the present six-volt generator. Further demands for still higher outputs, to meet improvements in lighting, air-conditioning, as well as for windscreen wipers, automatic dimming devices, and higher loads at slow engine speeds, can be fulfilled by changing to a 12-volt generator. As shown in Fig. 3, the 12-volt generator gives a 33 per cent gain in maximum watts output as well as a considerable improvement in slow-speed performance. To indicate how such improvements are possible by changing to higher voltage, it is necessary to consider briefly the design features of automotive generators.

The value of the field current which can be handled by the regulator contacts, which is a limiting factor, is about the same for 12 V as for 6 V. This means that the generator field resistance of the 12-V unit must be doubled, and this can be done by using more turns of smaller-gauge wire, resulting in a 25-30 per cent increase in field strength, which does not, however, appreciably affect the overall temperature of the generator. For 12-V operation, with stronger magnetic fields and certain modifications in the proportions of the magnetic paths, the number of armature conductors

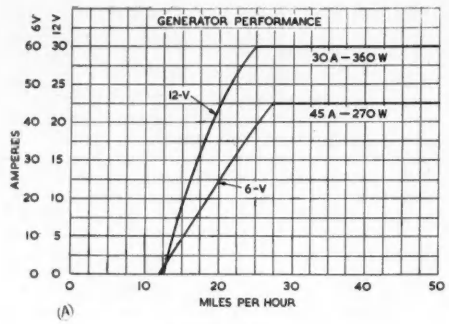


Fig. 3.

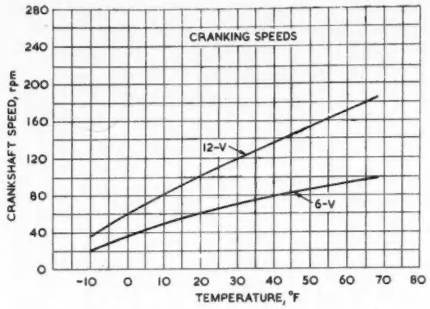


Fig. 4.

need only be increased by 60 per cent, so that the size of the conductors can be greater than half that used for 6 V. Therefore, the armature current will be more than half that of the 6-V unit, and the maximum watts output will be correspondingly greater.

The higher efficiency of the 12-V unit in the 12-25 mph region is particularly significant. A 1952 car equipped with a 12-V system and driven at night in a built-up area would have an electrical load of 23 A, which could be supplied by the generator at 20 mph, whereas a 6 V equipped 1952 model car would require 43 A, and have to travel at 27 mph for its generator to supply this load. This would not be likely under the conditions mentioned, particularly if streets are covered with snow or ice. At higher speeds, there is seven times as much energy available from the 12-V generator for storage in the battery than from the 6-V system (7 A at 12 V and 25 mph, compared with 2 A at 6 V and 28 mph). Thus, the 12-V system gives both better ignition and improved generator performance.

FASTER CRANKING SPEED

Increased cranking motor performance enabling engine starting under all weather conditions without extra attention is being desired by the public. The provision of a cranking motor for greater cranking speed would therefore be a wise solution. It is essential, however, to maintain the cranking motor at its present size so as to avoid any basic changes in engine blocks, flywheel housings, etc.

The best solution for the 12-V cranking motor seems to be a compromise design that would have less than double the number of turns of a 6-V motor. As this motor would draw more than half the current required by a 6-V motor, it would be necessary to use a higher wattage battery to provide sufficient cranking time.

A 12-V battery rated 70 Ah per cell can be made in a case only slightly larger than that of the present 6-V 17-plate battery rated 110 Ah per cell (i.e., it will have the same length, $\frac{1}{4}$ inch less height, $\frac{1}{4}$ inch more width). With its approximately 30 per cent greater storage capacity, this battery will not only provide better starting but also give improved assistance to the generator in carrying slow-speed loads with a less rapid discharge. The improved cranking speeds obtained with a 12-V motor and a higher-wattage battery are shown by the curves of Fig. 4.

The magnitude of the back e.m.f. available for producing speed of rotation is always extremely low in cranking motors owing to the high voltage drop occurring with extremely high current in the battery, cable, connections, motor fields, armature and brushes. To rotate the armature, only 1·1 volts are available in a 6-V motor. The corresponding back e.m.f. is 2·4 volts in the 12-V system, because of the lower current and higher initial voltage. Therefore, the voltage available with the latter for producing speed of rotation is more than doubled, and this almost doubles the cranking speed. The increase is not fully proportional to the back e.m.f. since the latter is opposed to some extent by a stronger field flux.

Thus, with the same distributor, same size coil, generator, and starting motor, together with a battery increased in size by only five per cent, the 12-volt electrical system is capable of giving considerable gains in ignition performance, higher generator output, and faster cranking speed.

RUSSIA

The 400 kV Kuibyshev-Moscow Transmission Line

By A. V. Minrolyubov and S. S. Rokotyan. (From *Elektritchestvo*, No. 7, 1952, pp. 6-10, 9 illustrations.)

The double-circuit transmission lines from Kuibyshev and from Stalingrad to Moscow are vital links in the power grid which is planned to interconnect all large electricity producing and electricity consuming centres in the U.S.S.R. The first of these lines was scheduled for erection in 1952 *and* 1953, *and this article discusses its main design features. This installation is of particular interest because it combines exceptional distance, capacity and voltage in a way which appears to be unique at present.*

For the transmission of power from the Kuibyshev water power station to Moscow over a distance exceeding 900 km, and also for a similar transmission to Moscow from the Stalingrad water power station, it is necessary to build two high-voltage transmission lines, each for a capacity of about 1·1 million kW. These transmission lines represent the first steps towards the creation of a single high-voltage grid which in a few years' time will cover most of the European part of the U.S.S.R., and it is claimed that they are the first lines of a comparable

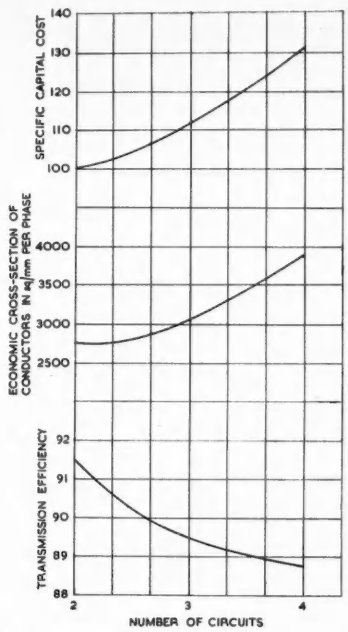


Fig. 1. **Economic parameters of the transmission line as functions of the number of parallel circuits.**

combination of capacity, length and voltage ever to have been designed or built anywhere in the world.

The capacity and length of these transmission lines, which will operate at 50-cycle a.c., necessitate a voltage higher than that at present used, and a nominal voltage of 400 kV was consequently chosen. A voltage of 360 kV which was also investigated proved to be unacceptable from the technical and economic points of view, because with two transmission circuits only, this voltage would not have provided the required degree of stability in parallel operation, and thus would have necessitated the provision of a third circuit.

Due to hydrological conditions, Kuibyshev power station operates during a certain number of hours per year at small and moderate loads. For this reason, the no-load losses on the long 400 kV line assume considerable importance; to increase the number of parallel circuits to transmit the same power would reduce the efficiency of the transmission.

Fig. 1 shows the calculated economic characteristics for one of the alternative designs for this line. These figures illustrate the reasons for the choice of two parallel circuits, each of 600,000 kW capacity.

The transmission line was designed to operate at optimum efficiency, to avoid the transmission of reactive power, and to prevent voltage surges at the input and receiving ends. To achieve this, shunt reactors of 400 kV and a combined capacity of 600,000 kVA will be provided at the input end and half-way along the line, and the receiving end will be equipped with large synchronous condensers.

To keep low the losses caused by the load current, the current density will be small compared with the density usually adopted for transmission lines of 110 and 220 kV. In the present project the current density, with both circuits working, has been chosen as 0·5-0·6 A/mm². The cross-section of the aluminium conductors of each cable is about 1500 mm². The annual power losses associated with the transmission of 6,100 million kWh will be as low as 4 to 4·5 per cent.

The maximum transmission capacity of a single 400 kV circuit, over a distance of between 800 and 1,000 km, in an electrical system with normal characteristics, does not normally exceed 200,000 kW. Therefore, special arrangements had to be provided to increase the capacity of this line to 600,000 kW per circuit, and at the same time to ensure the static and dynamic stability of parallel operation of the synchronous machines associated with this line. These measures include the following :—

(a) Automatic regulation of the excitation of the synchronous machines. The excitation of the generators is so regulated that a constant e.m.f. is maintained under operating conditions.

(b) The use of low-reactance generators and transformers.

(c) Provision of triple conductors in order to reduce the line inductance.

(d) Compensation of inductance by means of batteries of series condensers. This compensation will balance between 30 and 40 per cent of the line inductance.

(e) The installation of large synchronous condensers at the receiving end, also provided with rapid automatic regulation.

(f) The provision of switching stations which divide the transmission line into four sections.

(g) The installation of high-speed switchgear and a system of protective relays which together ensure the disconnection of a faulty section within less than 0·1 sec.

(h) Several measures to increase the dynamic stability in parallel operation : the neutral of the 400 kV input transformers is earthed over a small ohmic resistance; the generators have ultra-rapid excitation control; a three-phase loading resistance can be connected to the 400 kV bus-bar system of the Kuibyshev station for short periods.

Curves showing the maximum transmission capacity of this line, determined by the condition of static stability, are given in Fig. 2 as function of the degree of compensation of line inductance.

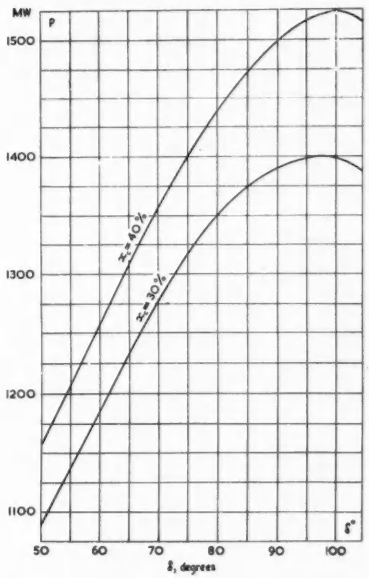


Fig. 2. **Maximum transmission capacity as function of static stability. x_c —percentage compensation of line inductance by series condensers.**

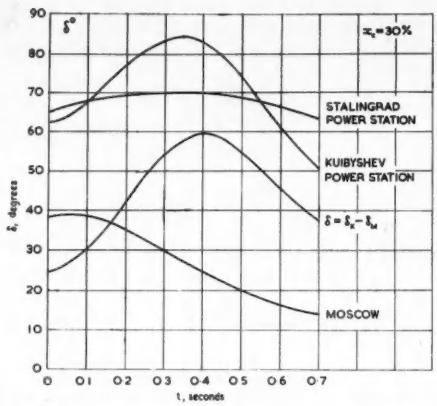


Fig. 3. **Behaviour of phase angles of equivalent generator e.m.f.'s after three-phase short-circuit near the 400 kV bus-bars at Kuibyshev.**

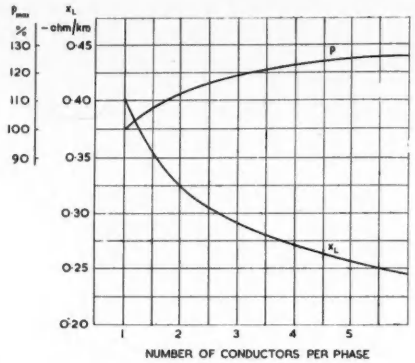


Fig. 4. **Inductance and transmission capacity of 400 kV transmission line with different numbers of conductors per phase.**

Fig. 3 shows the expected behaviour of the phase angle of equivalent generator e.m.f.'s, following a three-phase short-circuit near the 400 kV bus-bars of the Kuibyshev station. The fault is assumed to occur at instant zero and to be cleared after 0·12 sec. At 0·16 sec., the loading resistance is switched in for a short time, to be switched off again at 0·50 sec.

The transmission capacity and the inductance of one 400 kV circuit as a function of the number of parallel conductors in each phase is shown in Fig. 4.

The circuit diagram of the double-circuit transmission line in single-phase representation is shown in Fig. 5. It shows three switching stations and four batteries of series condensers for line compensation, each situated roughly half-way between two adjacent switching stations. An alternative arrangement, with the condensers placed directly in the switching stations has also been considered.

At the receiving end, the 400 kV line is connected to several 400/115 kV sub-stations. This improves safety of operation, and at the same time provides the most favourable conditions for the development of the 110 kV and 220 kV distribution system in the Moscow region.

The transmission line from Stalingrad water power station to Moscow will differ from the Kuibyshev-Moscow line only insofar as one of the intermediate switching stations will be designed as a 400/115 kV transformer station to supply the central Black Earth region.

The insulation levels of the 400 kV system are determined by the following basic conditions :—

(a) The neutrals of the 400 kV windings of the power transformers are solidly earthed.

(b) The highest line voltage in operation is 420 kV.

(c) The transmission line is protected over its entire length by two earth wires with a protective angle between 15 and 20 degrees.

(d) The transformer stations are likewise protected against direct strokes.

(e) The transformer stations are provided with cathode-type lightning arresters.

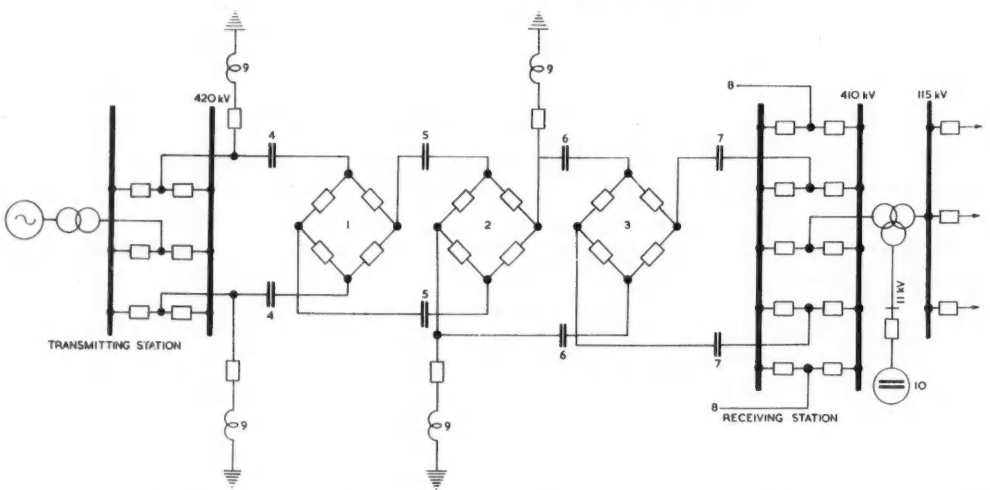


Fig. 5. **Circuit diagram of double-circuit power transmission between Kuibyshev and Moscow.**

(f) The magnitude of internal overvoltage does not exceed

3 U phase, max, where U phase, max = 343 kV.

(g) The impulse test voltage applied to the transmission line installation is one-third higher than the impulse test voltage of the internal insulation of the equipment.

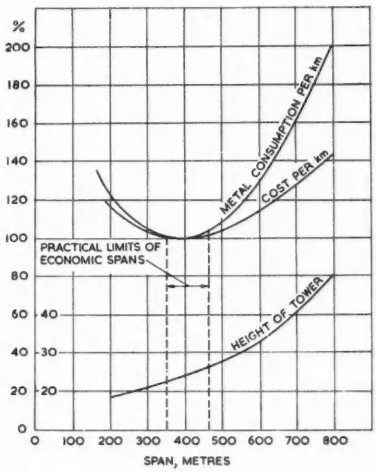


Fig. 6. **Selection of optimum span height of tower.**

The following are further details describing the transmission line. The total length of the line is 925 km. Each steel-reinforced aluminium conductor is of 30·2 mm diameter, has a weight of 1,800 kg/km, and a break load of 14,300 kg. The three conductors of each phase are spaced in triangular formation at a distance of 400 mm from each other (Fig. 6).

Strings of 22 porcelain insulators are used; the elements are tested for a load of 7 tons for regions with a mild climate and 8·5 tons for regions with severe winters. Insulator strings for anchor towers and angle towers consist of 22 insulators of slightly larger size, tested to a load of 11 tons. Arcing rings are used. The earthing resistance of each tower must not exceed 10 ohms.

The towers are of welded construction in open-hearth steel of low carbon content. Since the 400 kV transmission line will transmit large amounts of power and will be heavily stressed mechanically, an accurate study of the optimum height of towers, their best structural design, and the optimum average span was carried out. Fig. 7 shows the graphs forming the basis for the choice of the span and the height of the suspension towers. The towers of the portal type (Fig. 8) were found to be the most favourable with regard to steel economy, ease of erection, convenience of maintenance, transport cost and weight of foundation. A suspension tower weighs 7·25 tons; the height of the point of support of the insulator string is 27 m above ground, and the total height of the tower is 29·8 m. The three phases are mounted in horizontal formation with a spacing between phases of 12 m. The normal span is 425-460 m.

Each of the two legs of anchor and angle towers is of "tripod" construction (Fig. 9). The height of the point of support of the insulator string is 22·2 m and the total height of the tower 29·6 m.

The weights of anchor and angle towers of different types are :—

Type of Tower	*Weight in Tons*
Anchor and angle (0-15 deg)	13·1
Angle (15-30 deg) ..	16·5
Angle (30-45 deg) ..	16·6
Angle (45-60 deg) ..	17·8

The foundations for suspension towers in normal ground are of reinforced concrete cast on the site. The foundations of anchor and angle towers are of prefabricated concrete.

The construction of the two transmission lines will require the following volume of work and materials :—

Earth work	700,000 m³
Concrete work	200,000 m³
Metal structures	45,000 tons
Conductors, etc.	35,000 tons

At the receiving end in the Moscow region several transformer stations will be built to step down the voltage to 115 kV without intermediate transformation to 220 kV. The transformer stations will, however, also comprise transformers for 220/115 kV to provide a link with the existing 220 kV system.

The transformer stations will also have hydrogen-cooled synchronous condensers. In spite of the severe climatic conditions in the Moscow region, it has been decided to install these machines outdoors. With the 400 kV and 220 kV transformers will be associated on-load voltage regulating transformers. The substation structures of all voltage levels will be outdoors. The spacing between the 400 kV bus-bars is 25 m; the height of the supporting structures is 28 m and their width 16·5 m.

The following are the main technical data of the equipment to be installed: The rating of the step-up transformers is 370,000 kVA, for a bank of three single-phase units, the voltages being 13·8/420 or 13·8/121/420 kV. The windings are $\Delta/Y/Y$ connected, the neutral of the 420 kV windings being earthed either solidly or over a small ohmic resistance. The step-up transformers have forced oil circulation and are water-cooled.

The rating of the step-down transformers is 300,000 kVA per bank; the windings are $\Delta/Y/Y$ connected, with the neutral of the 410 kV winding solidly earthed. These transformers are air-cooled. The 400 kV circuit breakers are of the air-blast type, rated for 2,000 and 1,000A. The rupturing capacity is 10 million kVA, and the rupturing speed three cycles. Other types of 400 kV circuit breakers are also being tested. The 400 kV isolating switches are of the blade type designed for 2,000 and 1,500 A nominal current; they are operated by a.c. motors.

The 400 kV voltage transformers are of the cascade type, of accuracy class 0·5 and capacity 300 VA. The current transformers are of the bar type, with a ratio 2,000-1,000-400/1. The lightning arresters are either of the post or the suspension type.

The series condensers will be of outdoor construction and at line voltage to ground. The voltage of the synchronous condensers is 11 kV, their rating 75,000 kVA and their speed 600 rpm.

Some of the design data of this transmission system were derived from laboratory tests with, as far as possible, full-scale prototypes of equipment operating on simulated sections of transmission line. In the first half of 1952, these tests were completed and the equipment is now in production. The transmission line, the step-down transformer stations and the switching stations are already under construction.

Press Tools with Plastic Mass

By E. G. KOPENEVIECH. (From *Stanki i Instrument*, No. 3, 1952, pp. 28-29, 5 illustrations.)

PRESS tools for producing components which require auxiliary punches at an angle to the main punch can become complicated and unreliable in operation. In such cases, the design of the press tool can be simplified and its operation improved by the use of plastic mass to transmit pressures around corners.

In Fig. 2, a compound press tool is shown which performs in one operation the bending of the leaf ends and the forming of the bottom of the component shown in Fig. 1. The blank, in the shape of a flat cross, is placed in the template (13). When the ram is lowered, its first action is to bend the arms of the cross. The punch (3) which performs this operation is fixed in the punch holder (15), which is solidly connected with the intermediate plate (6) of the die set. In this plate, two bushes (5) are fitted, by which the plate is guided along the columns (1). In the bending operation, the ram load is transmitted to the punch (3) through two coil springs (4) preloaded to a force exceeding the bending effort. At the instant when the bending of the leaves is completed and the spherical cup of the component is formed in the die (14), the intermediate plate (6) butts against the faces of the guide bushes (7) and stops. The ram of the press together with the upper plate of the die set continue their downward movement. As a result of this motion, the springs (4) are further compressed, the pins (2) come up against plungers (8), and the latter exert a pressure on the plastic mass, which fills the annular space between the base plate (11) and the ring (9).

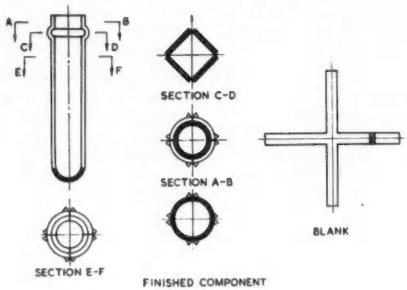


Fig. 1

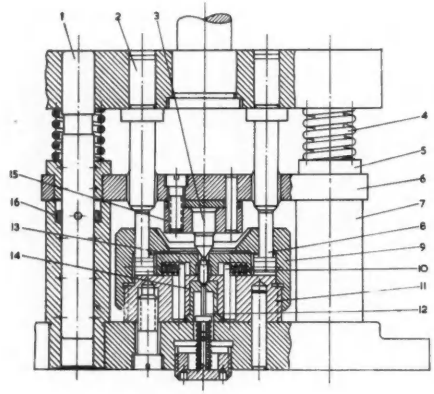


Fig. 2

The plastic mass transmits the pressure to the rear faces of the forming punches (10), which move towards the centre and thereby form the ends of the leaves. When the ram is raised, the pressure on the plastic mass is released and springs withdraw the side punches (10) to their initial position. At the same time as the intermediate plate (6) is raised, the ejector pin (12) ejects the finished part from its nest in the base (11). The leaves of the component open up slightly owing to spring-back, and the component, not being clipped in the punch, falls off. The intermediate plate (6) is raised together with the upper part of the die set owing to collars (16) provided on columns (1).

The superiority of the press tool shown here, in comparison with a conventional design which incorporates a wedge mechanism, lies in the elimination of very accurate fitting work needed to ensure equal pressure on both lateral punches (10). Equalisation of pressure is ensured by the hydrostatic property of the plastic mass. This ensures that the centre punch (3) will not be loaded in bending. In designing the side punches actuated by the plastic mass, the mechanical efficiency of the transmission can be assumed to be 80 per cent.

In Fig. 3 a press tool is shown which performs the piercing of eight holes in a pressed cup component. When the ram is lowered, the centre piece (1) comes down and butts against buttons (2). These ensure precise location of the centre piece against the boss (3) of the die block, an essential feature for proper functioning of the piercing punches. The intermediate plate (4) stops together with the centre piece. As the ram is lowered further, the springs (5) are compressed and plunger (6) exerts pressure on the plastic mass, which fills the hollow space in the centre piece (1). The plastic mass transmits the pressure to the annular faces of the piercing punches (7). The eight punches perform the piercing operation simultaneously. The off-cuts are pushed through the holes in the boss (3) of the die block and fall through the central opening. After the piercing operation, the punch block is raised, the pressure on the plastic mass is released, and the punches are withdrawn to their initial position by the springs and studs (8).

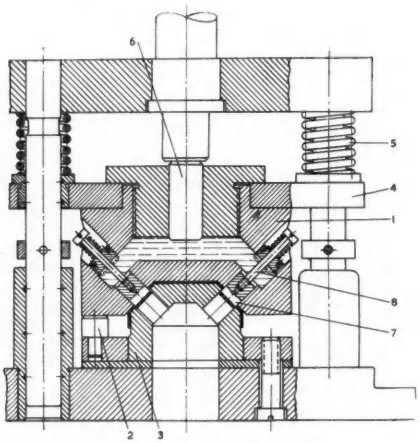


Fig. 3

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

ELECTRIC MACHINERY

Studies of Selenium and Its Alloys

By T. Satō and H. Kaneko. (From *The Technology Reports of the Tohoku University, Japan*, Vol. 16, No. 2, 1952, pp. 18-33, 30 illustrations.)

The remarkable improvement in recent years on the power of selenium rectifiers has been largely due to the studies on selenium itself. The present paper is one part of a systematic investigation on the properties of selenium as a material for rectifiers. The study from this point of view involves many problems, but this paper deals chiefly with the purity and electrical conductivity of molten selenium. The former has a clearly marked effect on improving the rectifying character, so that the problem of the purification of selenium is of great importance. The method of purifying selenium which is used now on an industrial scale is distillation ; therefore, it is necessary to determine the vapour pressure of selenium containing some impurities. This is the first subject of this paper. As regards electrical conductivity, the problem is that of determining the change of conductivity due to some impurities. In a previous report,* the present authors determined the conductivity of selenium in the solid state, and in this work they experienced some difficulties in measuring owing to the unstable contact resistance between solid selenium and electrode. In the present work, the authors have attempted to determine it in a molten state, and as a result of this experiment, the so-called doping and anti-doping actions of some impurities have been made clear.

FUEL ENGINEERING

Wet Combustion

By K. N. Cederquist and P. Bering. (From *Acta Polytechnica, Sweden*, Chemistry including Metallurgy Series, Vol. 3, No. 1, 34 pages, 40 illustrations.)

In many countries with insufficient supply of fuel, peat has been considered a possible substitute for coal, but in spite of many efforts no satisfactory method of utilisation has been found. This is due to the high water content, 85-95 per cent, of the crude peat, and to the difficulty of removing the water by filtration and pressing. For a long time it has been known that the filtration properties can be materially improved by heating the peat suspension to temperatures of some 200° C, but technical problems, particularly heat transfer, have turned out to be serious obstacles in the development of industrial methods.

Now it has been found that many of those technical problems can be overcome by a new technique, called wet combustion, the main principle of which is oxidation of wet peat by oxygen or air at a temperature of 170-200° C and a pressure of 15-30 kg/cm². By " burning " 10-20 per cent of the crude solids, enough heat is evolved to raise the temperature of the whole mass to such a level that a reaction takes place by which the filterability of the slurry is increased by a factor of 50 to 100.

Two systems for carrying out this reaction have been designed and various factors, such as the consumption of oxygen, heat and rate of reaction as well as different technical problems have been studied both in the laboratory and in a pilot plant. Methods for analysing the various operations and for calculating the performance of equipment have been developed, the results being condensed into diagrams and nomographs.

Finally, a few applications particularly gasification are discussed.

*Satō and Kaneko, Technology Reports, Tohoku Univ. (Japan), 15 (1950), 1.

GAS TURBINES

Some General Considerations in the Design of Axial-Flow Gas Turbines

By S. Alpert. (From *SAE Quarterly Transactions, U.S.A.*, Vol. 6, No. 4, October, 1952, pp. 606-616, 16 illustrations.)

Fundamental considerations, primarily of an aerodynamic nature, which are involved in the design of the turbine component of the gas turbine engine, are discussed by the author. He has achieved a practical outline on a basic level by limiting his material to the general techniques that will be of immediate interest to the turbine designer.

He first discusses the fixed design conditions concerning temperatures and pressures, and then divides the design problem into two parts :

(1) Determination of the velocity diagrams,
(2) Design of the blade profiles to yield those velocity diagrams.

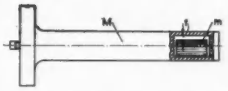
The discussion of the second part of the problem includes the evaluation of four types of the most commonly accepted profile design methods. He then points out that aerodynamics, stress, mechanics, fabrication, and assembly must all be considered together to achieve the best possible design of the turbine.

MACHINE TOOLS

Vibration Absorber with Impact Action and its use in Machine Tools

By L. B. Erlikh. (From *Stanki i Instrument, Russia*, No. 7, 1952, pp. 17-19, 5 illustrations.)

Among different methods of reducing the intensity of vibrations, a method based on the dissipation of energy through the impact of imperfectly elastic bodies has not had sufficient attention. It is claimed that such vibration absorbers surpass other dissipative types in the simplicity of their design, the reliability of their functioning and the convenience of their application.



The laws of impact show that for maximum dissipation in a single impact between two bodies having the masses m and M, the ratio m/M should be as large as possible and the velocities of the two masses equal and opposite at the moment of impact. A vibration absorber of this type simply consists of a slug of metal moving freely in an enclosed space. The mass of the slug should be at least one third of the mass of the vibrating body. For any given vibration there is an optimum clearance between the slug and the walls of the hollow space against which impact takes place.

It has been possible to embody this type of vibration absorber in a carbide slug inside the spindle of a pre-

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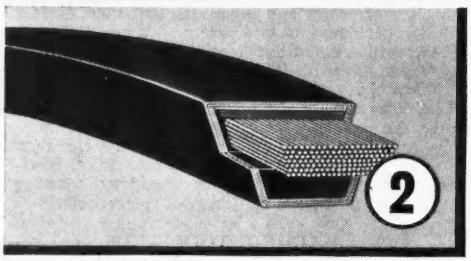
The "Stacker" belt illustrated here is designed for installations which handle highly abrasive materials. Its tough resilient cover "gives" under impact and resists cutting. High grade bonding between the plies prevents separation under severe flexing. It is proofed against the ruining effects of mildew.



2 RAYON CORD V-BELTS

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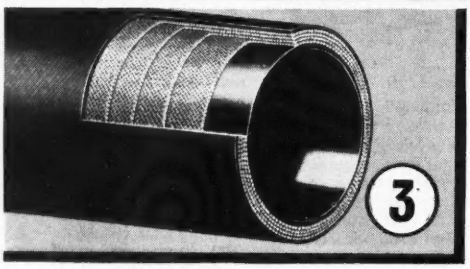

3 WRAPPED PLY HOSE

This Goodyear Hose is built from high-grade rubber tube wrapped in tough rubberized fabric for greater strength. A protective cover of bruise- and abrasion-resisting rubber assures lasting wear. And scientific arrangement of the fabric plies minimizes kinking. Intended for general service this wrapped ply hose gives long life under the most arduous conditions.

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cision boring mill. The design is shown semi-diagrammatically in the accompanying illustration. Since the boring bar does not move bodily in its principal mode of vibration, an equivalent mass must be substituted for its total mass. The result is that a slug having one tenth of the total weight of the boring bar is effective. At a suitable clearance f which was derived from experience, it was found possible to increase the overhang of a boring bar using diamond cutting tools for high-precision work, which was previously restricted to four diameters, to a value of eight diameters, without detriment to precision or smoothness of the machined surface.

METALLURGICAL ENGINEERING

Thermoelectric Force—Accurate Measuring Methods and Applications to the Study of the Heterogeneity of Alloy Structures.

By F. AUBERTIN and C. CRUSSARD. (From *La Metallurgia Italiana, Italy*, Vol. 46, No. 11, November, 1952, pp. 548-559, 25 illustrations.)

CONTINUING their study on the variations of thermoelectric force of metals with the changes in structure, the authors have developed some accurate measuring methods.

Such measures have been applied to the study of the concentration heterogeneity in solid solutions of aluminium alloys. The results obtained have shown that the formation of segregations of atoms continuously released from the solid solution produces an important positive or negative thermoelectric force variation. This variation has been observed also during ageing and rapid dissolution of finely dispersed precipitates. In this case a hardening has also been observed in extremely dilute solutions, near the dissolving precipitates, caused by the formation of zones rich in free atoms.

These researches have been extended also to the field of steels; the formation of carbon-rich zones has been highlighted both in ageing after tempering of mild steels and during the dissolution of a finely dispersed carbide precipitate. Both processes are accompanied by hardening. Some applications have also been made to the problem of brittleness (blue and temper brittleness).

NUCLEONICS

Construction of Nuclear Equipment at the ACEC.

By M. HOYAUX. (From *ACEC Charleroi, Belgium*, No. 2, 1952, pp. 31-48, 46 illustrations.)

THE author describes in considerable detail the work of the ACEC scientific and technical staff in connection with Ion Sources, Particle Accelerators and Detectors, Mass Spectographs and Isotope Separators and Measuring Instruments for Installation in High Vacuum.

The number of applications for nucleonic equipment has been increasing inexorably since 1948 when ACEC has created a Nuclear Equipment Centre in Belgium. At the same time, an increasing number of engineers have become interested in the industrial possibilities of nuclear equipment. Therefore, the author endeavours to present the subject in a style which is not too technical and specialised to be followed by readers who are not nuclear physicists.

THERMODYNAMICS

Performance of Finned Tubes in Shell-and-Tube Heat Exchangers

By R. B. WILLIAMS and D. L. KATZ. (From *Transactions of the ASME, U.S.A.*, Vol. 74, No. 8, November, 1952, pp. 1307-1320, 23 illustrations.)

HEAT-TRANSFER measurements have been made on three pairs of tube bundles. The bundles of a pair are identical except that plain tubes are used in one bundle and finned tubes in the other. The finned tubes have from 2·07 to 2·76 times as much outside surface as the plain tubes. Heat-transfer measurements were made for water, lubricating oil, and glycerine on the shell side. Several temperature levels and temperature differences were used to give a variety of viscosities and other fluid properties. Shell-side coefficients were determined by extrapolating to infinite water velocity the over-all coefficients for a series of water velocities inside the tubes. These shell-side coefficients are correlated by the following equation

$$\frac{h_o D}{k} = C\left(\frac{DG_m}{\mu}\right)^{0.65}\left(\frac{C_p\mu}{k}\right)^{0.375}\left(\frac{\mu}{\mu_w}\right)^{0.14}$$

where h_0 = outside coefficient based on outside area for plain tubes and effective outside area for finned tubes, D = diameter of tube, k = thermal conductivity, G_m = mean flow rate, shell side, μ = fluid viscosity at bulk temperature, μ_w = fluid viscosity at tube-wall temperature, and C_p = heat capacity. The values of C depend upon the bundle and vary from 0·225 to 0·143. The pressure-drop data are correlated by the methods presented by Donohue. The heat transferred per degree of temperature difference for the clean finned-tube bundles varied from 110 per cent of that for the corresponding plain-tube bundles for water to 200 per cent for the lubricating oil. For the same mass velocity, the shell-side coefficients for the finned tubes based on the outside area are approximately 80 $\pm$ 20 per cent of the plain-tube coefficients. In all cases, at the same mass velocities the pressure drop is less for the finned-tube bundles.

WELDING

Temper Brittleness in Low-Alloy Steel Weld Metal

By R. P. WENTWORTH and H. C. CAMPBELL. (From *The Welding Journal, U.S.A.*, Vol. 31, No. 11, November, 1952, pp. 505s-514s, 12 illustrations.)

THE temper-brittleness phenomenon has been investigated in five low-hydrogen low-alloy weld metal compositions. A slow notch-bend test was developed in order to give a ductile-or-brittle (pass-or-fail) indication. By the use of two criteria—fracture appearance and percentage contraction in width of specimen beneath the notch—the isothermal development of temper brittleness could be studied.

This test revealed temper brittleness in two Ni-Mo-V grades; it was less serious in the 100,000 psi grade than in the 120,000 psi grade. The range of embrittlement was 1050 to 1150° F in the 100,000 psi grade, as compared to 950 to 1250° F in the 120,000 psi grade. Long tempering times (over 10 hr) at 1200° F improved the ductility of the 120,000 psi grade, and considerably shorter times at 1250 and 1300° F also improved the ductility. Ductility was completely restored by holding at these higher temperatures for 2 to 4 hr.

It was also demonstrated that if the weld metal was initially rendered ductile by heating above the temper-brittle range, the ductility could be retained in spite of heating in the temper-brittle range (950 to 1150° F). A 1650° F austenitising heat treatment also appeared to be beneficial for 120,000 psi Ni-Mo-V weld metal, as it narrowed the temper-brittle range.

Temper brittleness was not revealed in tests of three other low-hydrogen electrode grades. Two Mn-Mo grades (low and medium carbon) gave completely ductile fractures. Type 2 Cr—½ Mo weld metal, because of its high as-welded hardness, required tempering at 1100° F or above to achieve satisfactory ductility.

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